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UNITED STATES ATOMIC ENERGY COMMISSION

INFLUENCE OF SHIELD CONFIGURATION ON CARGO CAPACITY OF NUCLEAR POWERED SHIPS

By
O. H. Klepper

January 16, 1956

Newport News Shipbuilding
and Dry Dock Company
Newport News, Virginia

Technical Information Extension, Oak Ridge, Tennessee

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INFLUENCE OF SHIELD CONFIGURATION
ON CARGO CAPACITY
OF NUCLEAR POWERED SHIPS

JANUARY 16, 1956

NEWPORT NEWS SHIPBUILDING
AND DRY DOCK COMPANY

Written by: O. H. Klepper
Reviewed by: D. A. Holden

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I. INTRODUCTION

This report consists in part of work done by the Newport News Shipbuilding and Dry Dock Company under the November 4, 1953 -November 4, 1955 agreement with the Atomic Energy Commission to study the application of atomic energy to surface ships. This is not the final report.

A. Objectives

The purpose of this report is to make a comparison of cargo carrying capacity and approximate gross revenue of (1), a nuclear powered cargo ships and (2), a nuclear powered tanker, using lead, oil, and structure for secondary shielding.

It was decided to include in this study a reactor plant with a stand-by oil-fired boiler, and a reactor plant with an oil-fired superheater to determine the weight and space requirements for fuel oil shielding.

B. Scope

The C4-S1-A Mariner is the cargo ship and a 707 ft. bulk oil carrier is the tanker for which the designs have been prepared. Table V lists some of the principal characteristics of these ships. The Mariner has been a reference design of previous reports, while the tanker was selected since it is a recent design of a large tanker for which detail information was readily available.

Listed below are the five designs studied.

Ship I is a nuclear powered Mariner, reactor compartment shielded by lead and hydrogenous material.

Ship II is identical with Ship I, except that cargo oil and ballast tanks surround the reactor compartment. It is an attempt to replace the secondary lead shield of Ship I with revenue producing cargo oil.

Ship III is a nuclear powered Mariner utilizing fuel oil and ballast instead of lead, as shield material. The reactor plant was reduced in size to produce the same total shaft horsepower as Ship I in conjunction with an oil-fired superheater.

Ship IV was included to show what effect a stand-by oil-fired boiler and fuel oil would have on the secondary shield weight and on the vessels cargo capacity. The purpose of the boiler would be to bring the ship into port at reduced speed after reactor plant failure, and to provide ship's service power when the reactor is shutdown.

Ship V is a nuclear powered 707 ft. oil tanker. Cargo oil and ballast tanks make up the secondary shield.

For comparison, machinery, fuel oil, and cargo deadweight have also been estimated for an oil-fired Mariner and Tanker, and are included in the tables.

II. DISCUSSION OF DESIGNS

A. Ship I

1. Reactor Plant

The reactor selected for this study is a single pass light water moderated and reflected, pressurized water design as indicated in Reference 1. There are 4 vertical integral drum boilers and loops, and 1 canned rotor centrifugal pump per loop. Primary coolant pressure is 2000 psig at 542°F. average temperature.

The reactor compartment arrangement is shown in Figure 1. The containment vessel consists of a 28 ft. diameter 0.8125" thick steel cylinder with ellipsoidal ends, designed to contain the gases should there be a break in the primary coolant system.

Personnel access will be provided by portable plugs in the lead shield, and a bolted manhole in the containment vessel. Replacement of equipment such as coolant pumps or the core would necessitate cutting an opening into the containment vessel.

2. Steam Plant

The design follows conventional marine steam plant practice with the following exceptions:

(a) Use of saturated steam, 555 psig at throttle.

(b) Addition of a reheater between HP and LP main turbine stages, and 2.5 psia condenser vacuum, both to limit moisture in the turbine.

(c) 1500 KW coolant pumping power required for the reactor.

For a more complete description of the steam cycle see Reference 1.

A cross-compound turbine drives a single screw thru double-reduction gearing at a normal designed power of 17,500 SHP at 102 rpm and a maximum designed power of 22,000 SHP at 110 rpm.

The machinery arrangement is shown in Figs. 3 - 5.

3. Secondary Shield

The shield design has been based on the AEC tolerance weekly dose of 300 mr per week, assuming full 168 hours per week exposure, and full power operation at 80% of the time.

It consists of 0.8125" steel, 6.8" average thickness lead, 5.6" average thickness hydrogenous material, extending over the compartment sides above the tank top. To prevent backscattering into the machinery spaces 2 ft of water will be carried in the inner bottom tanks in way of the reactor compartment.

4. Cargo Capacity

Reactor and steam plant component weights are shown in Tables 1 and 2 respectively while total deadweight for each ship is shown in Table 3.

Heavier machinery, secondary shield, and deletion of settling tanks result in a total deadweight of 12426 tons, or 992 tons less than the oil-fired ship. For the purposes of this study it has been assumed that fuel oil deep tanks Frs. 24-36 and Frs. 172-184 can be converted to dry cargo holds at the conversion ratio of 27 cubic feet per ton, Reference 2, for a cubic gain of 13900 cubic feet over the oil-fired ship. Length of machinery space is the same for both the oil-fired and the nuclear powered ship.

In order to assess the effects of the changes in dead-weight and bale capacity on the earning ability of the designs, an arbitrary round trip voyage distance of 15000 miles was selected.

The number of revenue tons carried per trip, taking into account commodities of various densities, is estimated with the following equation taken from Reference 2.

$$\Delta_R = \frac{C_B}{50} + 0.5\,\Delta_C$$

where Δ_R = Number of revenue tons per trip

C_B = Available cubic volume in cubic feet

Δ_C = Available cargo deadweight in long tons

A rate of $30 per revenue ton of dry cargo was selected as a reasonable value for this distance.

To provide a yardstick, the cargo capacity and revenue of an oil-fired Mariner, Fig. 6, was estimated on the same basis. Fuel oil required to operate the ship at an average sea speed of 20 knots was estimated assuming fueling at the home port only, while fresh water and stores were assumed loaded at each port.

B. Ship II

1. Reactor Plant

The reactor plant is the same as Ship I. Personnel access will be provided through the innerbottom tanks, leading to a bolted manhole in the tank top inside the reactor compartment.

Replacement of equipment would require emptying the shield tanks and cutting adequate openings in the tanks and containment vessel.

Main steam and feed lines enter the containment vessel through lead shielded, oiltight trunks. A flexible pressure seal at the end of the trunks is designed to keep the gases within the containment vessel in case of a primary coolant system break.

2. Steam Plant

The steam plant is the same as that of Ship I. Arrangement is shown in Figs. 7-11, and 13.

3. Secondary Shield

The secondary shield is designed to utilize revenue cargo such as premium oils or latex, as shielding material, thereby eliminating the lead shield except for

17 tons at the top of the containment vessel, since it was impractical to maintain the full shield tank thickness in way of the Main Deck.

The shield consists of the inner ballast tanks #1-3, and outer cargo oil tanks #1 and 2. The cargo oil tanks are designed for oil having a flash point not lower than 150°F. Cofferdams isolate the tanks from the shell, ballast tanks, and cargo holds. Expansion trunks are required to keep the tanks filled to the top.

While loading cargo oil, the ballast tanks must be kept full until the corresponding oil tanks are completely filled. Ballast tanks can be emptied after the cargo tanks are full, but they must be refilled before cargo oil is discharged.

If the cargo oil available is sufficient to fill #2 cargo tank only, #1 cargo tank may be carried empty if ballast tanks #1 and #2 are full instead.

Cleaning and other work inside the cargo oil tanks and cofferdams may be carried out when the ballast tanks are full, however the ballast tanks may be entered only when the reactor is shut down.

The shield thicknesses are designed to give the same dose rate within the ship as the lead shield of Ship I. The shield facing the sides is thinner, since the dose rate at the outside of the hull is of concern only at low reactor power in port.

To determine the shield thickness required a pipe in the primary coolant loop, as close to the reactor as possible, is selected so that the N^{16} gamma activity will be near its maximum value. Assuming the pipe to be an infinite cylinder, the dose can be read directly from curves shown in Reference 3. The values are then corrected for the actual length of pipe. The dose is obtained considering the ballast tank full (7'-2" water thickness) while the cargo oil tank is empty, and then by considering the cargo oil tank full (7'-10" oil thickness at specific gravity 0.9) while the ballast tank is empty. The dose rates are 1.93 mr per hour for the ballast shield, and 2.01 mr per hour for the oil shield. Tolerance level is 2.01 mr per hour assuming 24 hours per day exposure with an 80% power factor.

For comparison, an equivalent lead shield thickness of 7.7" was calculated.

4. Cargo Capacity

The machinery space is 30 ft. longer than in Ship I in order to accomodate the shield tanks. The midship deckhouse is also longer to make up for former living space on the Second Deck displaced by shield tanks.

Bale capacity is 58,000 cubic ft. less, and total deadweight is 652 tons less than for the oil-fired ship.

Revenue was determined in the same manner as for Ship I. Revenue from the cargo shield tanks has been based on 2060 tons, (38.9 cubic ft. per ton) premium oil carried on outbound trip only, at a rate of $34 per ton.

Table 4 shows that the liquid shielded Ship II can carry 340 tons of cargo more than the lead shielded Ship I while outbound, and 697 tons less when inbound with ballast in shield tanks.

C. Ship III

1. Reactor Plant

The reactor is a pressurized water type similar to the reactor considered for Ship I, reduced in size to produce 138.5 mbh maximum continous power. There are 2 vertical integral drum boilers, 2 loops, and 2 canned rotor centrifugal pumps per loop. Only one pump per loop is required for full power operation, the second pump serving as stand-by. Primary coolant pressure is 2000 psig at 542°F average temperature. Arrangement is shown in Fig. 2.

A steel containment vessel encloses the reactor compartment as in the previous design.

Provision for personnel access and equipment replacement will be similar to Ship II. Room for shipping machinery and re-fueling has been provided in a vertical trunk from the house top to the 2nd Deck as shown in Fig. 17.

2. Steam Plant

An oil-fired superheater is included in the plant to superheat the reactor steam to 865 degrees F. at 600 psig, the same steam conditions as for the oil-fired Mariner.

Principal characteristics of the steam cycle selected are tabulated below. While it is not an optimum cycle, the weight and space requirements should be representative.

Steam Cycle

Design Condition	Max. Continous Power 22000 SHP
Reactor Heat Load	138.5 MBH
Reactor Steam Flow	172,000#/Hr
Reactor Steam Pressure	620# G. Sat.
Superheater & Economizer Heat Load	64.4 MBH
Superheater Steam Flow	163,000#/Hr
Superheater Steam Pressure	600 #G
Superheater Steam Temp.	865°F
Main Turbine Throttle Pressure	575 #G
Main Turbine Throttle Temp.	855°F
Main Turbine Vacuum	28.35" Hg.
No. of Feed Heaters	2
Economizer Feed Temp.	280°F
Lbs. Oil Burned per Hour	4960
Reactor Feed Temperature	420°F
Superheater Efficiency	70%
Overall Efficiency	24.3%

The design follows conventional marine practice except for 750 KW coolant pumping power required for the reactor.

A cross-compound turbine drives a single screw through double-reduction gearing at a normal power of 17,500 shp and a maximum design power of 22,000 shp at 110 rpm.

The machinery arrangement is shown in Figs. 14-17.

3. Secondary Shield

The shield was designed to contain sufficient superheater fuel oil to give about the same cruising range

as the oil-fired Mariner, reducing shielding lead required to 34 tons.

Four layers of tanks, each 30" deep, surround the containment vessel above the tank top. Only three layers, or a total fuel oil thickness of 7'-6" is required to reduce the radiation on the shield tank face to 2.01 mr per hour, thereby permitting liquid to be drawn off the fourth layer of tanks. Lead is required locally in way of higher intensity radiation where 7'-6" of oil shield is inadequate.

Expansion trunks will be required for the shield tanks to maintain the head.

As in the case of Ship II, no liquids need to be carried in the innerbottom tanks below the reactor compartment.

4. Cargo Capacity

The machinery space is 30 ft. longer than in Ship I in order to accomodate the superheater and the shield tanks. Bale capacity is therefore the same as for Ship II, or 58000 cubic feet less than the oil-fired ship. Total dead weight is 527 tons less.

1670 tons of fuel oil are required for the 15000 mile round trip, based on a daily consumption of 42.3 tons at 17,500 shaft horsepower, fueling at home port only.

At departure, inbound, 939 tons of fuel oil plus 442 tons of ballast, or a total of 1381 tons are carried. After 67 tons of fuel oil have been consumed enroute, ballast must be increased to 676 tons to provide three layers of full shield tanks or a total of 1548 tons. This weight has been used to determine the cargo deadweight inbound in Table 4. Any small amount of fresh water and stores consumed have been neglected.

Ship III therefore, carries 1205 tons of cargo less while outbound, and 1083 tons less inbound, than the lead shielded Ship I.

D. Ship IV

1. Reactor Plant

The reactor plant is the same as for Ship I.

2. Steam Plant

The steam plant is the same as for Ship I except for a stand-by oil-fired boiler capable of propelling the vessel at about 9 knots should the reactor plant fail. Other uses for the boiler would be to supply ship's service power, and reactor start-up power. During normal operation it would not be in use.

Maximum steam flow for the boiler is about 24000 pounds of saturated steam per hour at a pressure of 600 psig.

Machinery arrangement is shown in Figs. 18-21.

3. Secondary Shield

A minimum thickness of 7'-6" of fuel oil over the containment vessel heads results in shield tanks of 300 tons capacity and about 3200 miles endurance, while replacing 160 tons of lead and hydrogenous material. Secondary shielding clear of the tanks and in the inner-bottom is the same as for Ship I.

Expansion trunks will be required for the shield tanks.

4. Cargo Capacity

The stand-by boiler requires 12'-6" of additional machinery space, reducing bale capacity by 29400 cubic ft.

For the purpose of calculating cargo dead-weight and revenue, 300 tons of fuel oil are assumed aboard. If greater endurance is required, an additional 80 tons may be carried in the settling tanks, giving an endurance of 4000 miles.

Boiler, shield tank structure, and longer machinery space increase total dead weight by 67 tons over Ship I, however, cargo deadweight is 233 tons less.

E. Ship V

1. Reactor Plant

The reactor plant is the same as that of Ship I.

Pipes, cable, etc. are carried thru the shield tanks, inside oiltight lead shielded trunks.

Personnel access is provided by an oiltight trunk from the upper deck to the top of the containment vessel. Liquids fill the trunk in the same manner as the shield tanks except when access to the reactor is needed.

Openings will have to be cut in the shield tank structure for equipment replacement and refueling.

2. Steam Plant

The steam cycle is essentially the same as for Ship I, but modified to suit oil tanker practice.

A cross-compound turbine drives a single screw thru a double-reduction gearing at a normal power of 20000 shp at 102 rpm and a maximum designed power of 22000 shp at 105 rpm.

Machinery arrangement is shown in Figs. 22-24.

3. Secondary Shield

The reactor containment vessel is located within a shield tank which provides a minimum shield thickness of 7'-6" of liquid. Because cargo tanks must be entered regularly for cleaning, this tank has been designated for ballast, since it can only be entered when the reactor is shut down.

Cargo oil wing tanks Frs. 53-63 PS, and ℄ tanks Frs. 53-60-2/3 shield the reactor when the ballast tank is empty. Minimum shield thickness again is 7'-6", no lead being required.

With the compartmentation shown, the ballast shield tank must be full before cargo oil is withdrawn from any of the shield tanks.

Expansion trunks will be required for each compartment to insure full shield tanks.

The center vertical keel depth of 9'-6" will have to be decreased locally since the underside of the containment vessel is 7'-4" above baseline.

4. <u>Cargo Capacity</u>

As indicated in Figs. 25 and 26, the machinery space of the nuclear propelled tanker is 25 ft. shorter than one for an oil-fired plant. This was accomplished by deleting the boiler room and moving the main engines as far aft as the width of the ship would permit.

The after deckhouse was shortened correspondingly to keep accomodations clear of cargo tanks.

Reactor compartment and shield tanks are located immediately forward of the engine room cofferdam to reduce the length of piping and other connections to the reactor.

The pump room is 5'-3" longer since it will also contain the main cargo pump turbines, and perhaps a condenser.

Space previously allocated to fuel oil settling and wing tanks is used for cargo tanks, providing total cargo tank capacity sufficient to bring the ship down to the marks with gasoline cargo.

Weight increase of the nuclear machinery over the oil-fired ship, excluding secondary shielding, has been assumed the same as for Ship I, since the maximum designed shaft horsepower is the same for Ships I and V.

Hull structure weight was increased by about 226 tons including containment vessel and shield tanks. Structure forward of the cargo tanks has been assumed unchanged.

Total deadweight is therefore 405 tons less than for the oil-fired tanker.

As in the case of the cargo ships, cargo capacity and gross revenue for the nuclear powered ship and a duplicate oil-fired one were estimated. A round trip of 17000 miles as an average sea speed of 18 knots, and fueling at home port only were assumed.

Under these conditions, the nuclear fired tanker can carry 4215 more tons of cargo than the oil-fired tanker.

F. REVENUE AND PERMISSIBLE ADDITIONAL INVESTMENT

1. Dry Cargo Ships

Annual revenue and permissible additional investment for each design considered is shown in Table 6.

The number of voyages per year for Ships I - IV is based on 350 days per year that the ship is available for cargo, and that the average port time per voyage is 20 days. (Reference 2)

Assuming that all other ship costs remain unchanged, the permissible additional investment of nuclear powered ships, made possible by increased revenue, has been calculated for the shield configurations studied.

The following equation, taken from Reference 2 was used:

$$I_A + .02 I_A \times 20 + .0138\ I_A \times 20 = 20 \times \text{Annual Revenue Gain}$$

or

$$\underline{I_A = 11.90 \times \text{Annual Revenue Gain}}$$

where

I_A = permissible additional investment
Average interest rate 1.38% per year, based on a 75% mortgage at 3-1/2%.
Insurance assumed 2%. U. S. Government to assume any catastrophe risk.
Depreciation straight 5% per year.

Table 6 shows that the lead shielded Ship I shows a much larger revenue increment and permissible additional investment than the other shielding schemes for dry cargo ships.

Second best among the dry cargo designs is Ship IV, which permits about 3.5 million dollars less permissible additional investment than Ship I. The secondary shield of Ship IV contains 160 tons less of lead and hydrogenous material, allowing some saving in shield costs, but not sufficient to overcome the 3.5 million dollar advantage of Ship I.

Permissible additional investment for Ships II and III is $985,000 and minus $4,558,000 respectively.

2. Oil Tankers

Annual gross revenue increment and permissible additional investment for the nuclear powered tanker was determined in the same manner as for the Mariners, except that the number of voyages per year was based on 347.5 days per year that the ship is available for cargo, and that average port time per voyage is 2.25 days. (Reference 2)

Assuming a revenue of $10.80 per ton, the permissible additional investment is about 4.2 million dollars.

III. CONCLUSIONS

1. Liquid shielding is usually heavier than the equivalent lead shielding. Some of the reasons are listed below:

   a. Even though the liquids considered in this report have about the same shielding properties as lead for equal masses, a greater mass of liquid will be required per unit area of shielded surface because of the convex curvature of the shield. For a 28' diameter containment cylinder, this weight increase, using fuel oil, is about 15%.

   b. It is difficult to contour liquid shield thickness in accordance with the varying radiation intensities over the surface of the reactor compartment. Some areas therefore, are more heavily shielded than necessary.

   c. Liquid beyond the minimum required for shielding is required to provide the necessary shield thickness while a tank is being emptied.

   d. Shield tank framing has little effect on radiation yet adds considerable weight.

2. Cargo oil shielding can increase the cargo deadweight of a cargo ship. However, unless the liquid cargo is available in both directions of a given trade route, cargo deadweight per roundtrip is likely to be less than for the lead shielded ship.

3. The combination reactor plant and oil-fired superheater considered with Ship IV is penalized both in cargo deadweight and bale capacity compared to the lead shielded, all nuclear ship. Total shield weight changes only slightly with varying amounts of fuel oil.

4. Shield tank structure and liquid would be minimized by using a displacement system for filling and emptying cargo tanks. As far as is known, this has not been done with liquids approaching the density of fuel oil.

5. From a weight and space standpoint the oil tanker seems better suited to liquid shielding than the dry cargo ship since the usual cargo tanks of an oil tanker readily becomes a part of the secondary shield system.

6. Under the assumptions made in this study, a dense and compact secondary shield such as lead, is the best one for dry cargo ships from the standpoint of revenue.

TABLE I

REACTOR COMPARTMENT MACHINERY WEIGHTS

Item	Ships I,II,IV & V Fig. 1 Dry	Liquids	Total	Ship III Fig. 2 Dry	liquids	Total
Reactor	149,000	14,200	163,200	95,500	9,100	104,600
Primary Shield	148,000	95,000	243,000	103,000	65,500	168,500
Steam Generators	127,700	39,200	166,900	63,800	19,600	83,400
Pressurizer	30,100	7,750	37,850	15,000	3,900	18,900
Demineralizer	9,200	3,000	12,200	4,600	1,500	6,100
Regenerative Heat Exchanger	400	50	450	200	30	230
Non-Regen. Heat Exchanger	560	70	630	280	40	320
Coolant Pumps	184,000		184,000	92,000		92,000
Vacuum Pump	500		500	500		500
Primary Coolant Piping	90,000	14,700	104,700	45,000	7,300	52,300
Reactor Aux. Piping	31,200	4,500	35,700	15,600	2,200	17,800
Insulation (Exc. React. Gen. Stm.)	13,100		13,100	6,500		6,500
Total	783,760	178,470	962,230	441,980	109,170	551,150
Total Long Tons	350	80	430	197	49	246

Weights in pounds

TABLE II

STEAM PLANT WEIGHTS

	Ships I & II	Ship III	Ship IV
Mn. Turbine	38.0	44.4	38.0
Mn. Red. Gear & Spares	98.6	98.6	98.6
Mn. & Aux. Cond	35.0	57.0	35.0
Shaft, Brgs. Prop.	202.5	202.5	202.5
Boiler, Draft & F.O. System		115.0	47.0
Mn. Circ. System	15.4	21.6	15.4
Fd., Condte., F.W. & S.W. System	85.5	75.6	87.0
Steam & Exh. Piping	84.7	64.7	88.0
Misc.	112.8	112.8	112.8
Liquids	105	106.9	105.0
	778	899	829

Weights in long tons

TABLE 3

TOTAL DEADWEIGHT SUMMARY

	Oil Fired Mariner	Ship I	Ship II	Ship III	Ship IV	Oil Fired Tanker	Ship V
Reactor Compt. Mach'y, Incl. Primary Shield		430	430	246	430		*
Reactor Aux. Mach'y		31	31	22	31		*
Steam Mach'y	1,041	778	778	899	829		*
Hull Engineering	644	535	535	545	540		*
Mach'y Foundations	60	150	150	125	153		*
Structure Increases		24	456	401	58		226
Lead & Hydrogenous Secondary Shield		789	17	34	629		
Total	1,745	2,737	2,397	2,272	2,670		
Increase Over Oil Fired		992	652	527	925		405
Total Deadweight	13,418	12,426	12,766	12,891	12,493	38,911	38,506

Weights in long tons

*Increase over oil fired. Assumed same as Ship I = 179

TABLE 4

CARGO CAPACITY AND REVENUE SUMMARY

	15,000 Mile Round Trip					17,000 Mile Round Trip	
	OIL FIRED MARINER	SHIP I	SHIP II	SHIP III	SHIP IV	OIL FIRED TANKER	SHIP V
OUTBOUND							
Crew, Effects, Stores, & L.O.	372T	372T	372T	372T	372T	254T	254T
Fuel Oil	3,320T			1,670T	300T	4,620T	
Shielding Ballast, S.W.			0	0			
Cargo Oil			2,060T			34,037T	38,252T
Dry Cargo, Δc	9,726T	12,054T	10,334T	10,849T	11,821T		
Cargo Deadwt. Increment Over Oil Fired Ship		2,348T	2,688T	1,123T	2,095T		4,215T
Total Deadweight	13,418T	12,426T	12,766T	12,891T	12,493T	38,911T	38,506T
Bale Capacity (Ft^3)	767,000	780,900	709,000	709,000	751,500		
Dry Cargo Revenue Tons $= C_B/50 + 0.5\ \Delta c$	20,200	21,645	19,347	19,604	20,940		
Revenue: Dry Cargo $30/T	$606,000	$649,300	$580,400	$588,100	$628,200		
Cargo Oil $10.80/T						$367,600	$413,100
Premium Cargo Oil $34/T			$ 70,000				
Total Revenue Outbound	$606,000	$649,300	$650,400	$588,100	$628,200	$367,000	$413,000
INBOUND							
Crew, Effects, Stores, & L.O.	372T	372T	372T	372T	372T	254T	254T
Fuel Oil	1,865T			872T	300T	2,671T	
Shielding Ballast, S.W.			1,037T	676T			2,340T
Dry Cargo, Δc	11,181T	12,054T	11,357T	10,971T	11,821T		
Cargo Deadwt. Increment Over Oil Fired Ship		873T	176T	-210T	640T		
Total Deadweight	13,418T	12,426	12,766	12,891T	12,493T	38,911T	38,506T
Bale Capacity, (Ft^3)	767,000	780,900	709,000	709,000	751,500		
Dry Cargo Revenue Tons $= C_B/50 + 0.5\ \Delta c$	20,930	21,645	19,858	19,665	20,940		
Revenue: Dry Cargo $30/T	$628,000	$649,300	$595,700	$589,900	$628,200	0	0
Total Revenue Inbound	$628,000	$649,300	$595,700	$589,900	$628,200	0	0
Revenue Outbound + Inbound	$1,234,000	$1,298,600	$1,246,100	$1,178,000	$1,256,400	$367,000	$413,000
Revenue Increment Over Oil Fired Ship		$ 64,600	$ 12,100	$-56,000	$ 22,400		$ 46,000

TABLE 5

C4-S1-A Mariner Characteristics

Normal shaft horsepower	17,500
Maximum design shaft horsepower	22,000
Designed sea speed	20 knots
Length over all	564 feet
Beam, molded	76 feet
Depth, molded	44-1/2 feet
Load line displacement	21,093 tons
Load line draft	29 feet 10 inches

707 ft. Oil Tanker

Normal shaft horsepower	20,000
Maximum designed shaft horsepower	22,000
Designed sea speed	18 knots
Length over all	707 feet
Beam, molded	93 feet
Depth, molded	48 feet 6 inches
Load line displacement	49,660 tons
Load line draft	36 feet 7 inches

TABLE 6

REVENUE AND PERMISSIBLE ADDITIONAL INVESTMENT

Item	Ship I	15,000 Mile Round Trip Ship II	15,000 Mile Round Trip Ship III	Ship IV	17,000 Mile Round Trip Ship V
Revenue Increment over Oil-Fired Ship Per Voyage	$64,600	$12,100	-$56,000	$22,400	$46,000
Number of Voyages Per Year	6.84	6.84	6.84	6.84	7.74
Gross Revenue Increment Per Year	$441,900	$82,800	-$383,000	$153,200	$356,000
Permissible Additional Investment	$5,259,000	$985,000	-$4,558,000	$1,823,000	$4,236,000
Relative Percentage of Permissible Additional Investment	100%	19%	-87%	35%	---

V

List of Figures

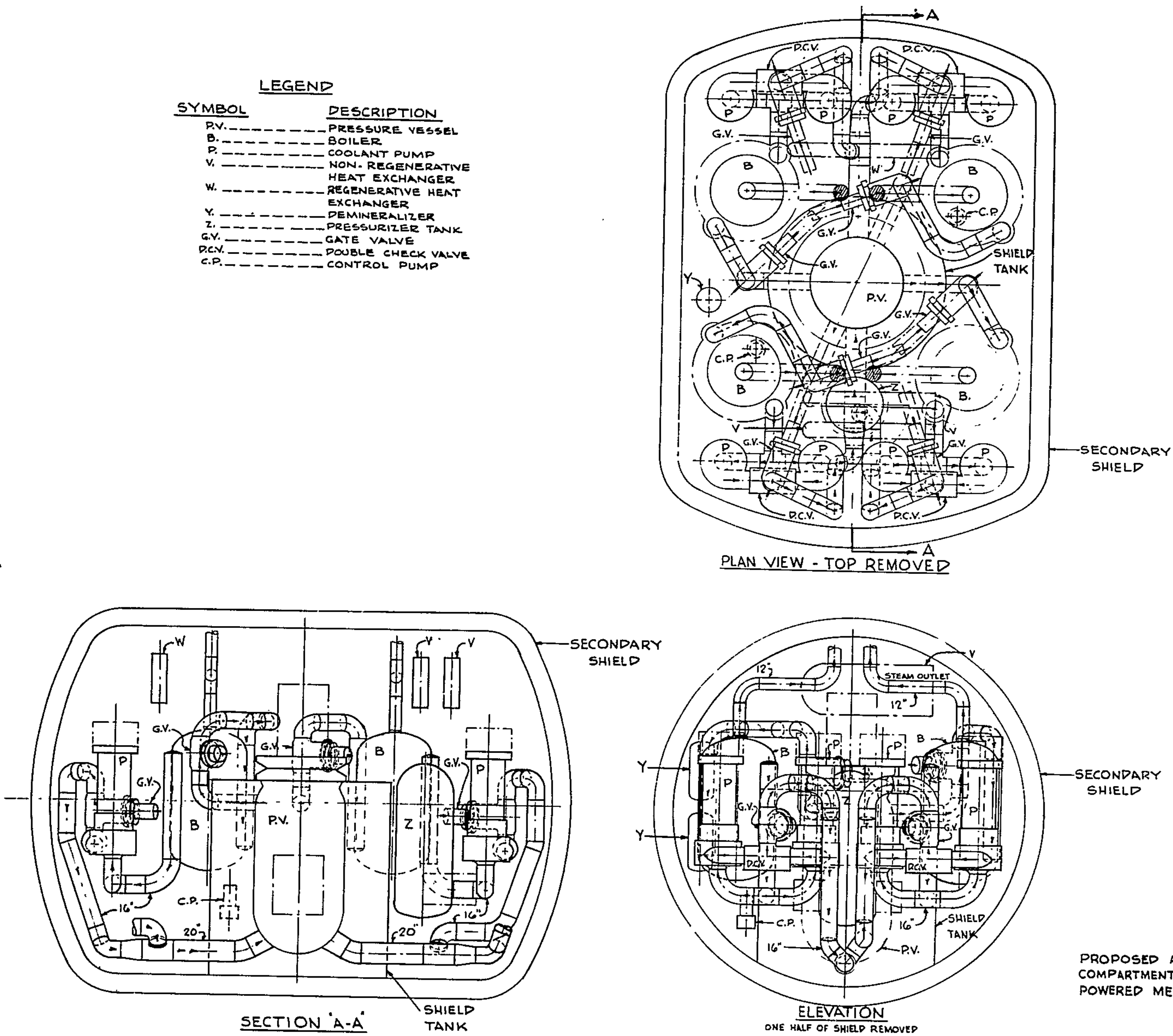
VI

References

1. NNSD-9 Newport News Shipbuilding and Dry Dock Company Interim Technical Report, July 1, 1954.

2. Preliminary Economic Report on the Application of Atomic Power to Merchant Ships, Parts I and II, NNS & DD Co.

3. WAPD RM 213.

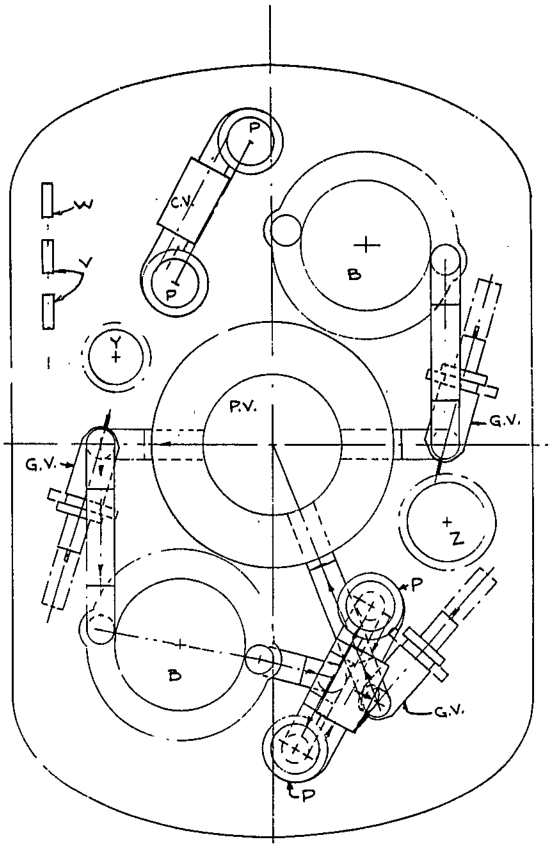


NOTE:
1. BOILERS SHOWN HEREON ARE OF B&W DESIGN SUBMITTED WITH THEIR LETTER OF 11-8-54.

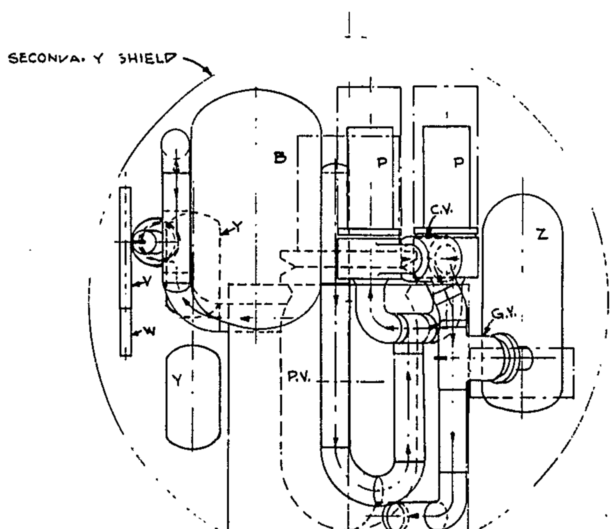
PROPOSED ARRG'T. OF REACTOR COMPARTMENT FOR NUCLEAR-POWERED MERCHANT SHIP

REACTOR COMPARTMENT ARRGT

FIGURE I



PLAN VIEW



ELEVATION
ONE-HALF OF SHIELD REMOVED

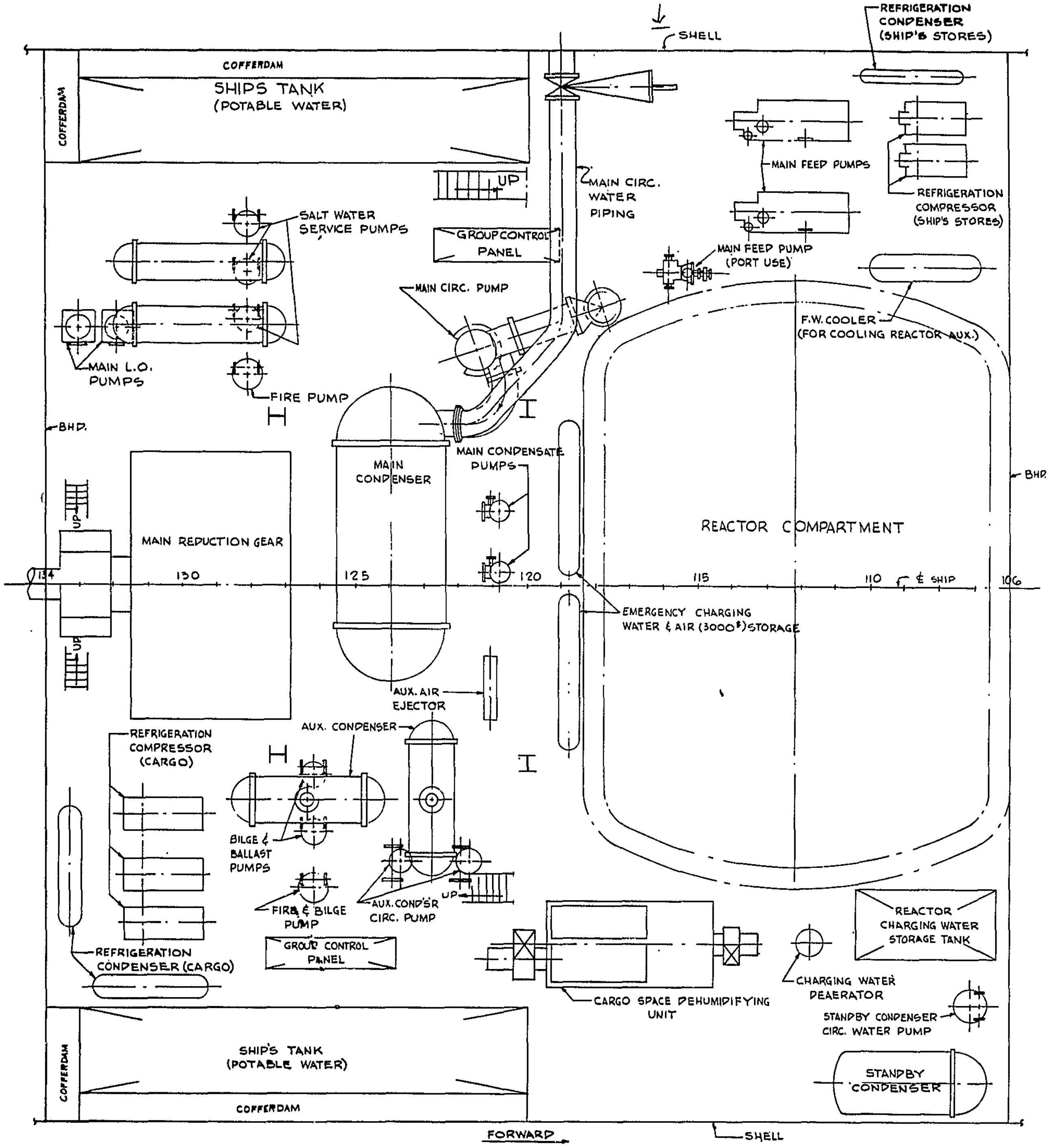
LEGEND

SYMBOL	DESCRIPTION
P.V.	PRESSURE VESSEL
B.	BOILER
P	COOLANT PUMP
V.	NON-REGENERATIVE HEAT EXCHANGER
W.	REGENERATIVE HEAT EXCHANGER
Y	DEMINERALIZER
G.V.	GATE VALVE
C.V.	CHECK VALVE
Z	PRESSURIZER

PROPOSED REACTOR COMPARTMENT FOR MERCHANT SHIP POWERED BY REACTOR & OIL FIRED SUPERHEATER.

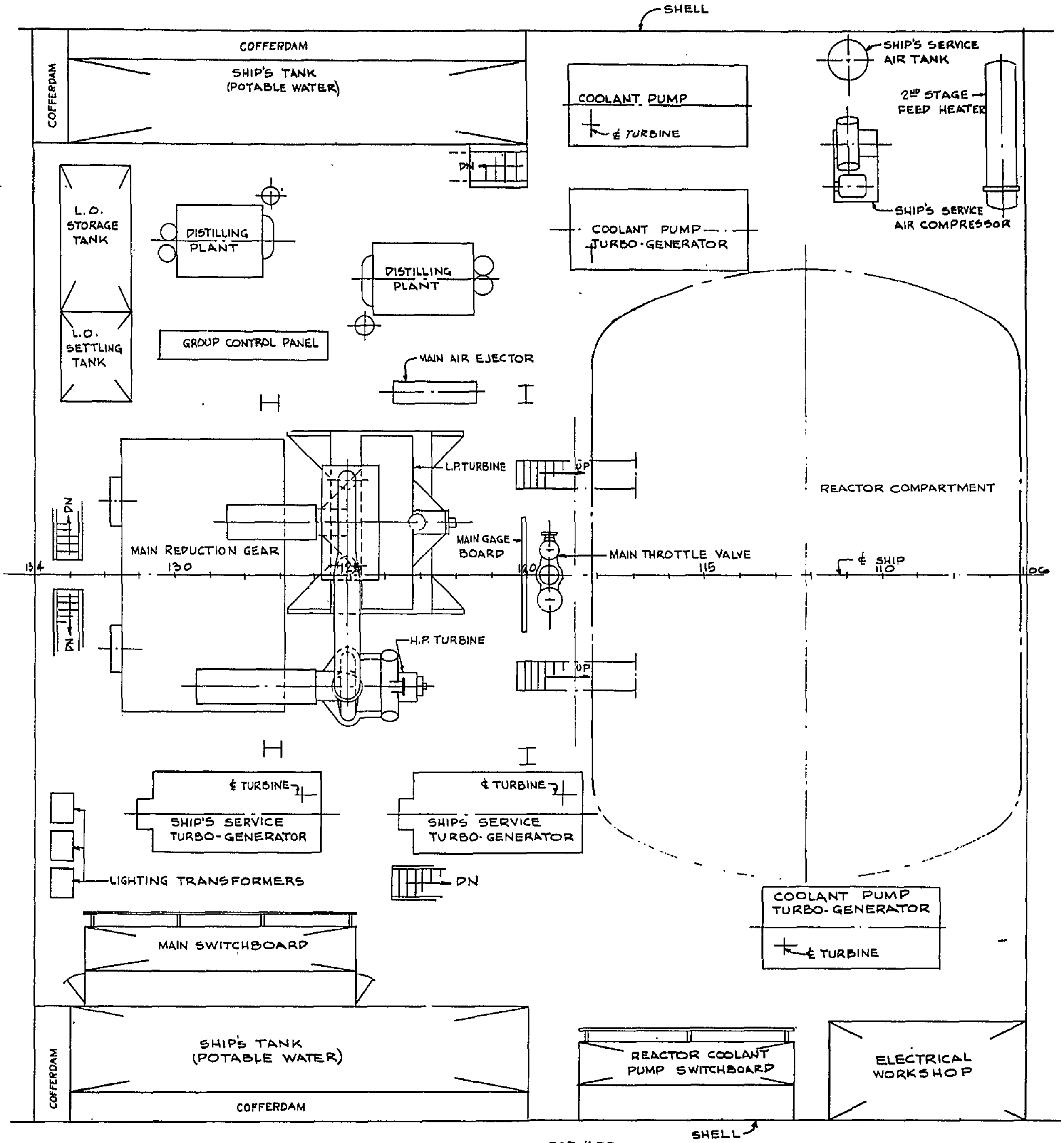
DRAWN: B. JONES
8-24-55

FIG. NO. 2



PLAN VIEW
LOWER LEVEL

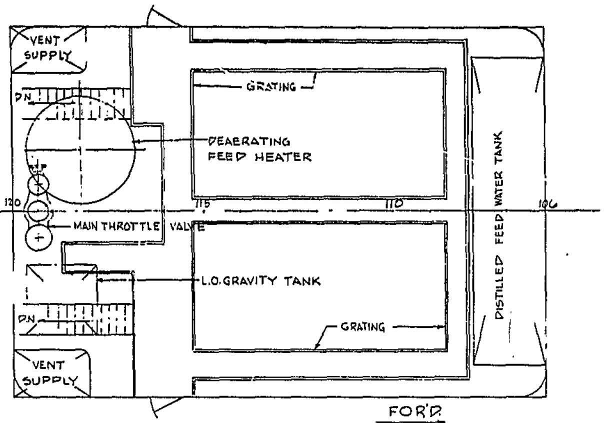
FIGURE 3



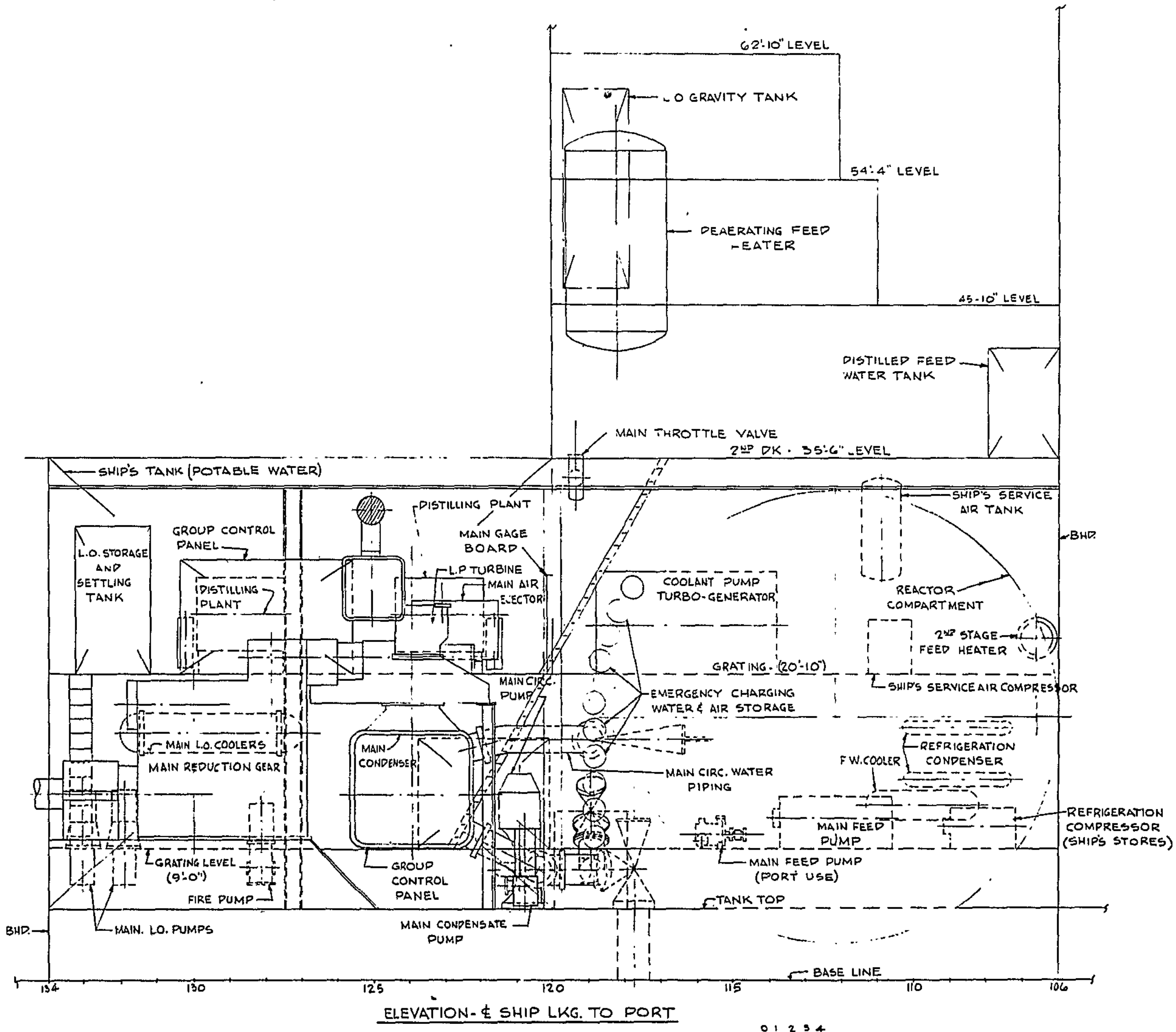
FORWARD

PLAN VIEW
UPPER LEVEL (20'-10") 0 1 2 3 4

FIGURE 4

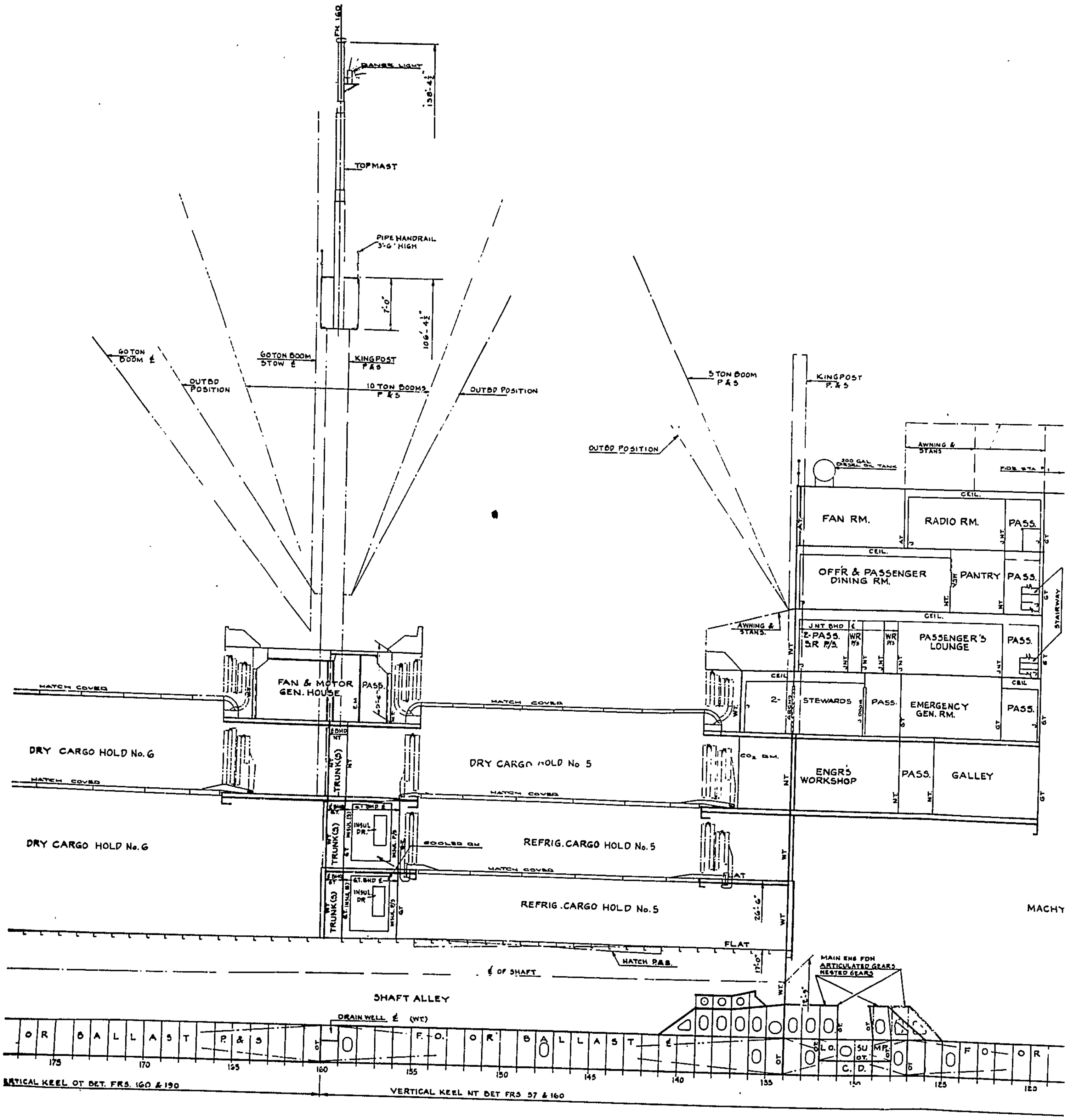


PLAN VIEW
35'-6" LEVEL



ELEVATION - ℄ SHIP LKG. TO PORT

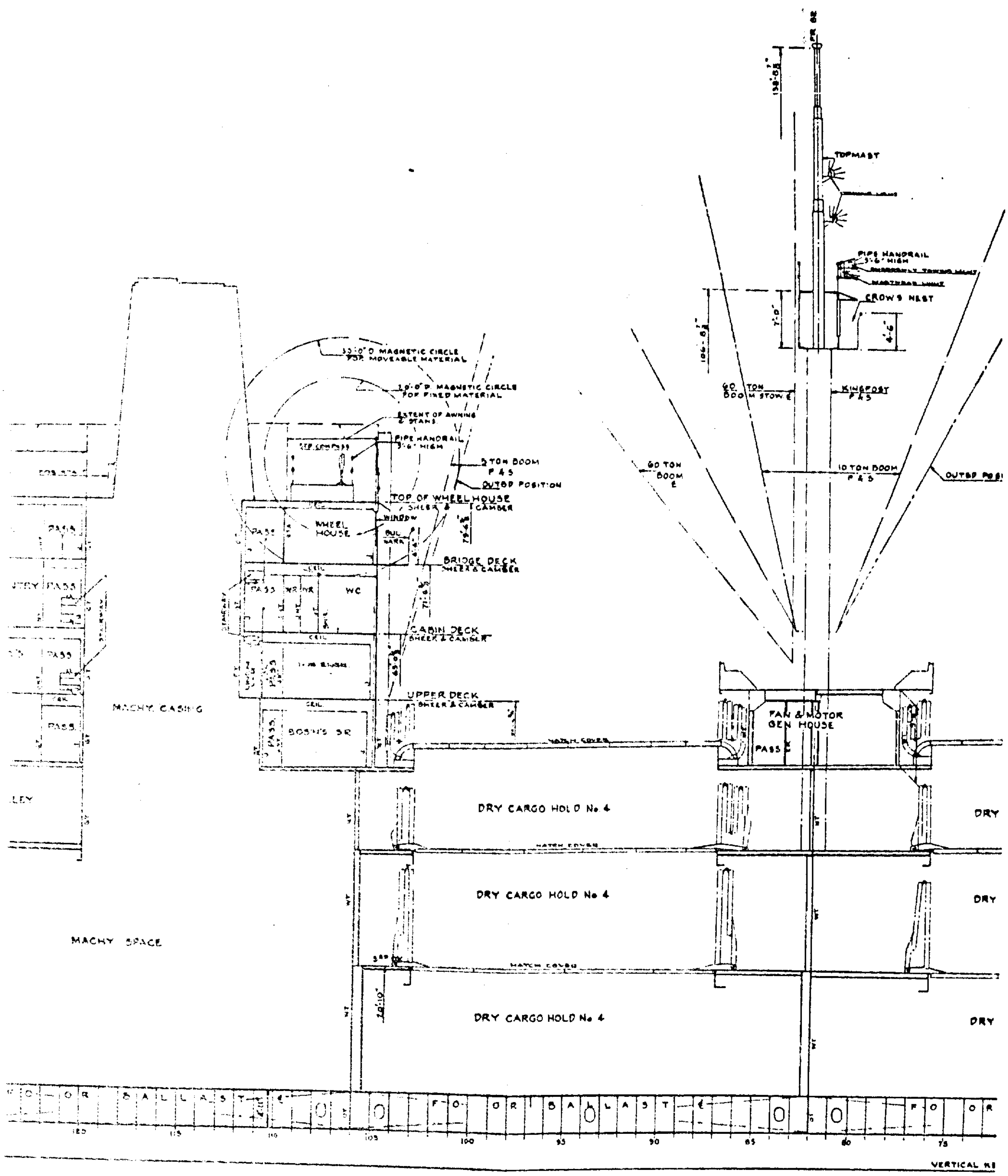
FIGURE 5



OIL-FIRED

ELEVATION

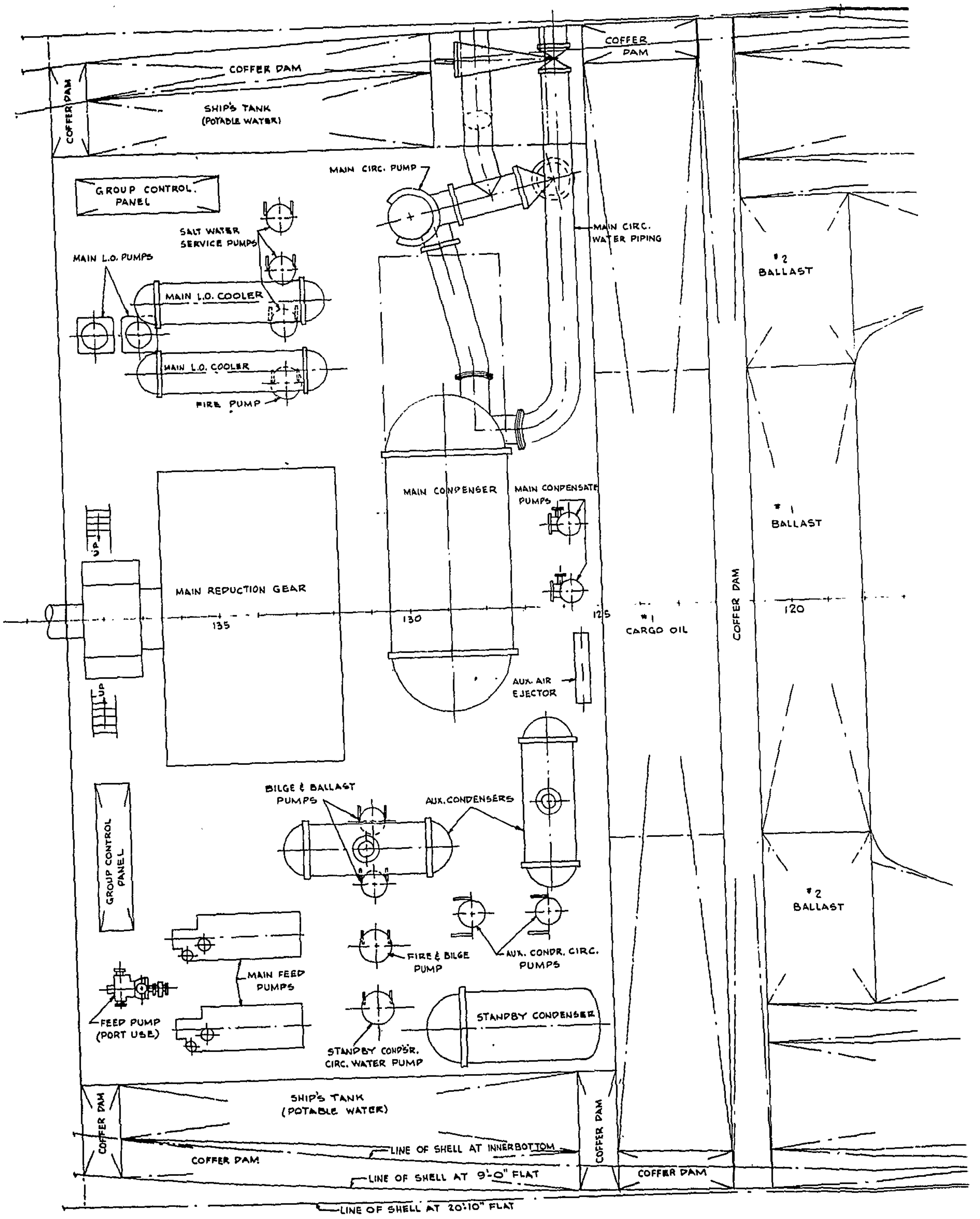
S NO. 6



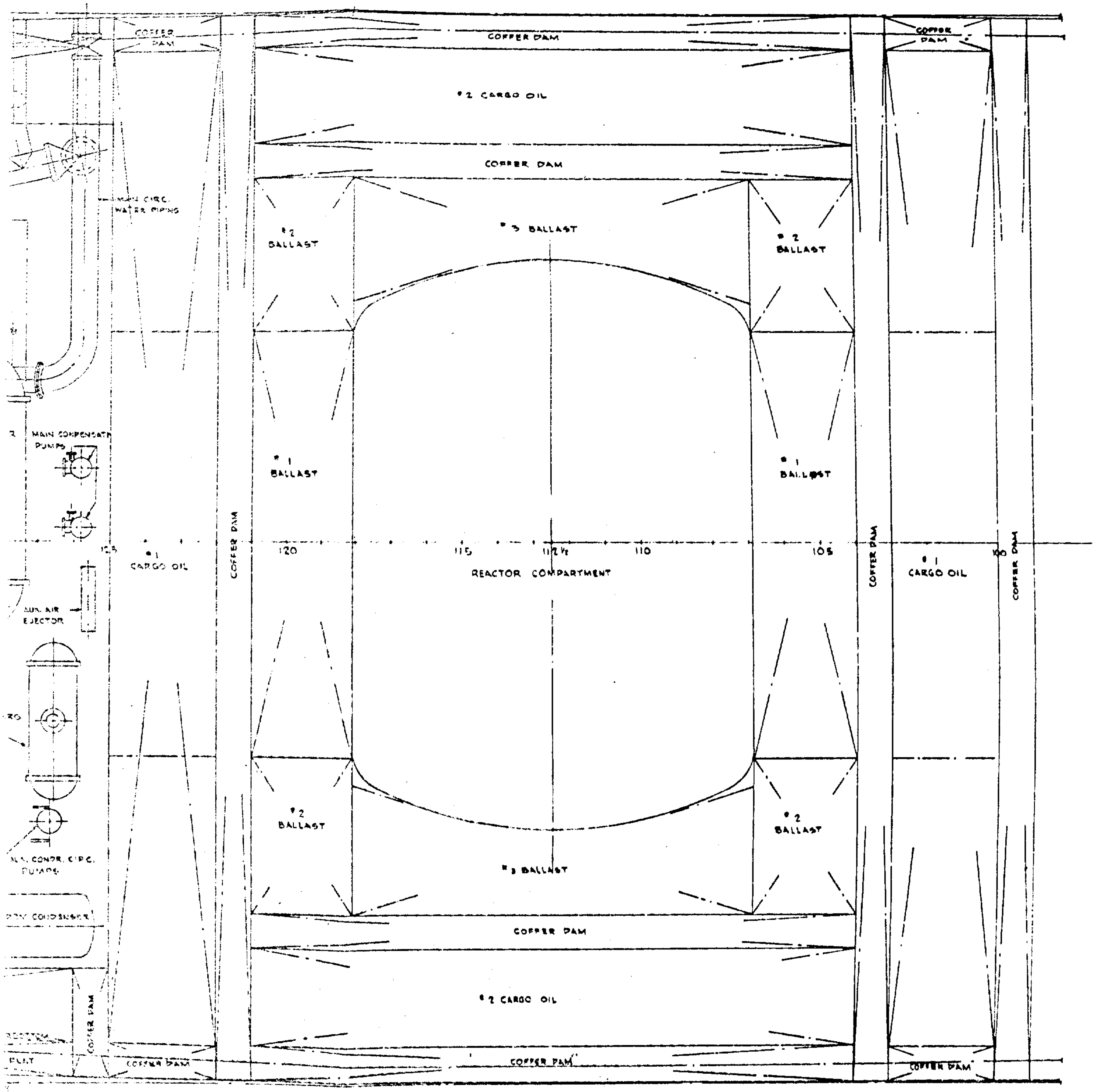
OIL-FIRED MARINER

ELEVATION

P D NO 6

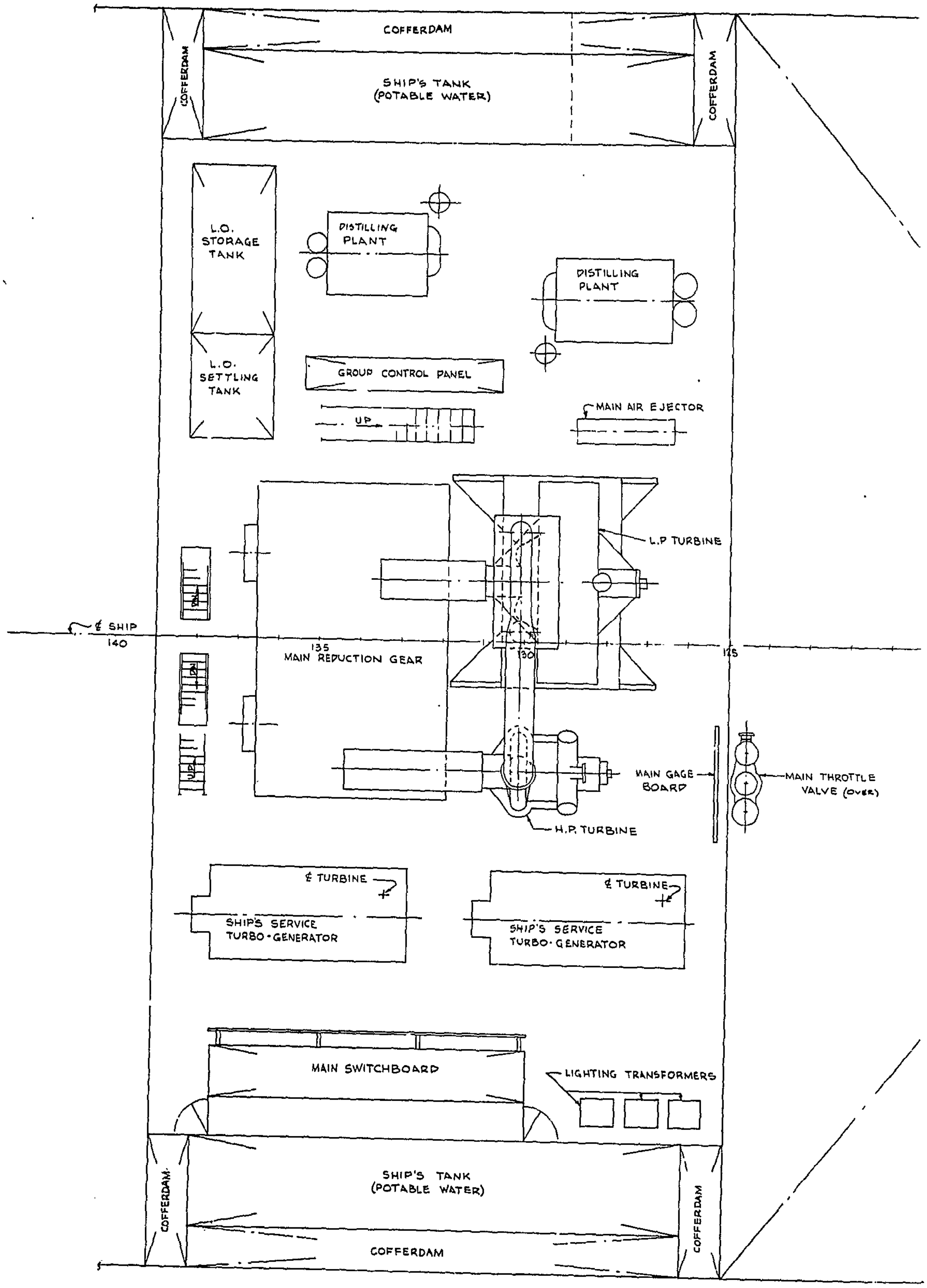


PLAN VIEW
MACHINERY ARR'GT.- LOWER LEVEL
(ABT. 9'-0" ABV. ℄.)

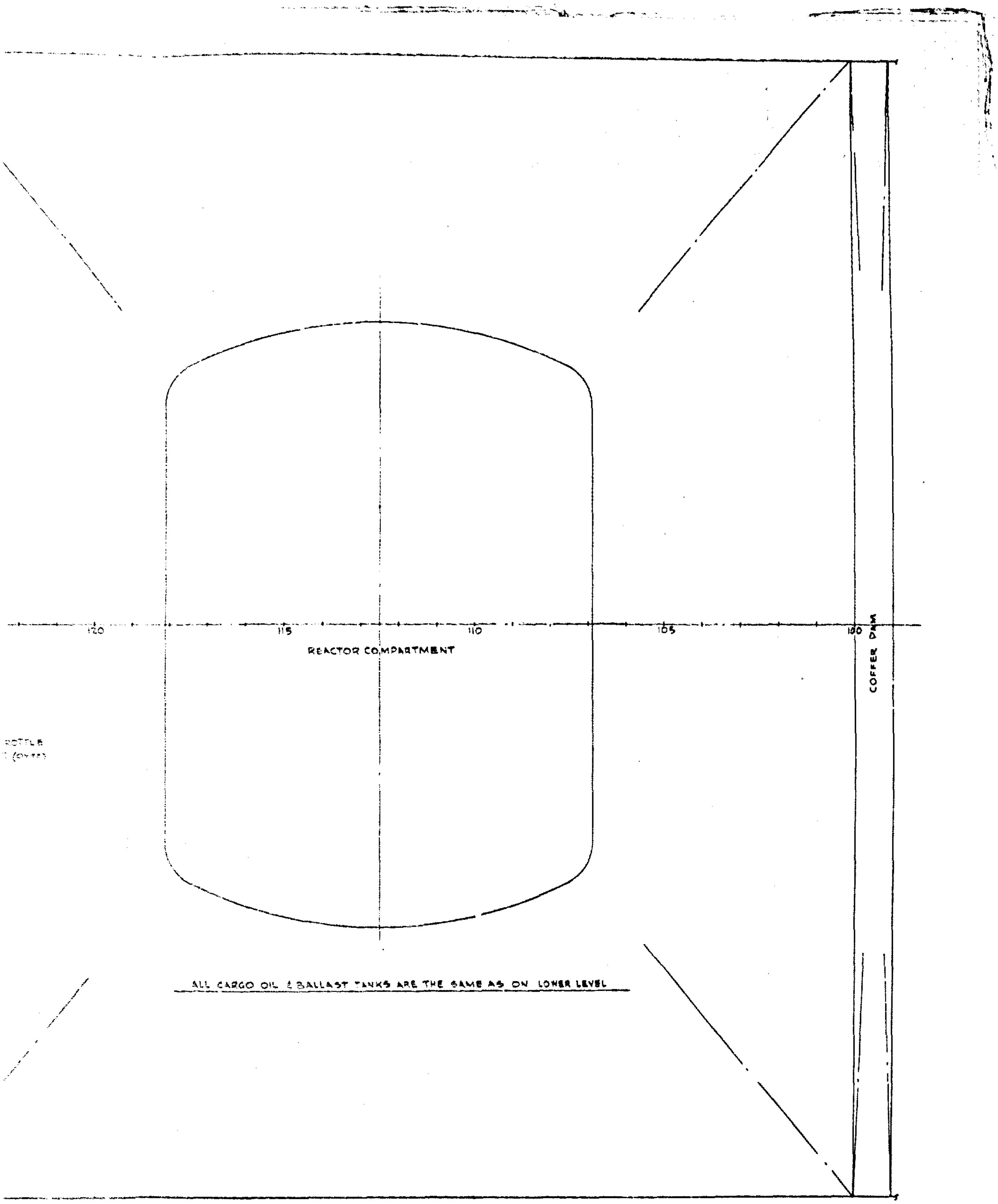


PLAN VIEW
MACHINERY ARRGT.- LOWER LEVEL
(ABT. 9'-0" ABV. ℄.)

FIG NO. 7

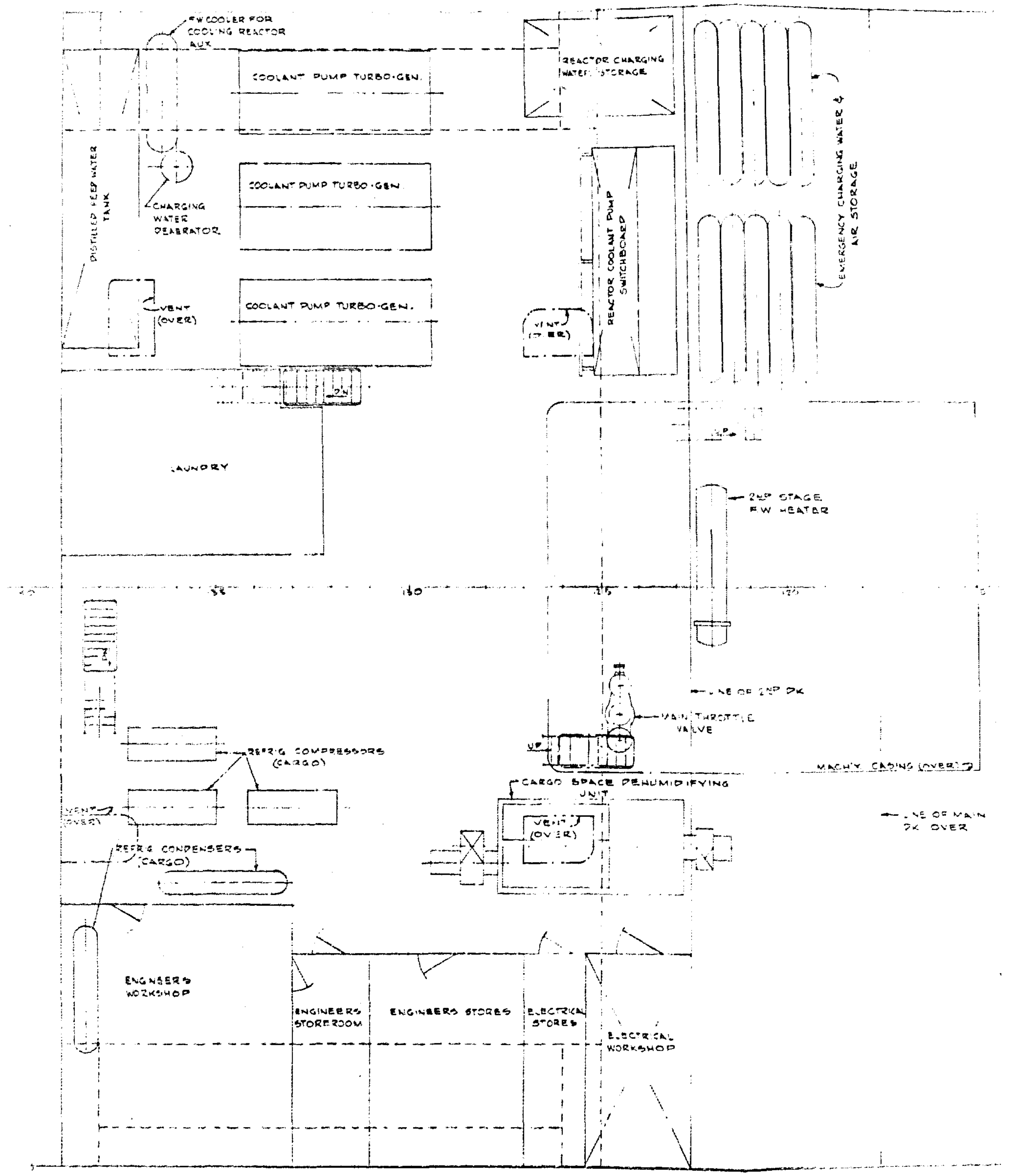

COFFERDAM
SHIP'S TANK
(POTABLE WATER)
COFFERDAM
COFFERDAM
L.O.
STORAGE
TANK
DISTILLING
PLANT
DISTILLING
PLANT
L.O.
SETTLING
TANK
GROUP CONTROL PANEL
UP
MAIN AIR EJECTOR
L.P TURBINE
℄ SHIP
140
135
MAIN REDUCTION GEAR
130
125
DN
DN
UP
MAIN GAGE
BOARD
MAIN THROTTLE
VALVE (OVER)
H.P. TURBINE
℄ TURBINE
SHIP'S SERVICE
TURBO-GENERATOR
℄ TURBINE
SHIP'S SERVICE
TURBO-GENERATOR
MAIN SWITCHBOARD
LIGHTING TRANSFORMERS
SHIP'S TANK
(POTABLE WATER)
COFFERDAM
COFFERDAM
COFFERDAM

MACHINERY



PLAN VIEW
MACHINERY ARR'G'T - UPPER LEVEL
(20'-10" ABV. ℄)

FIG. NO. 8



PLAN VIEW

MACHINERY ARR'GT - 2ND DECK

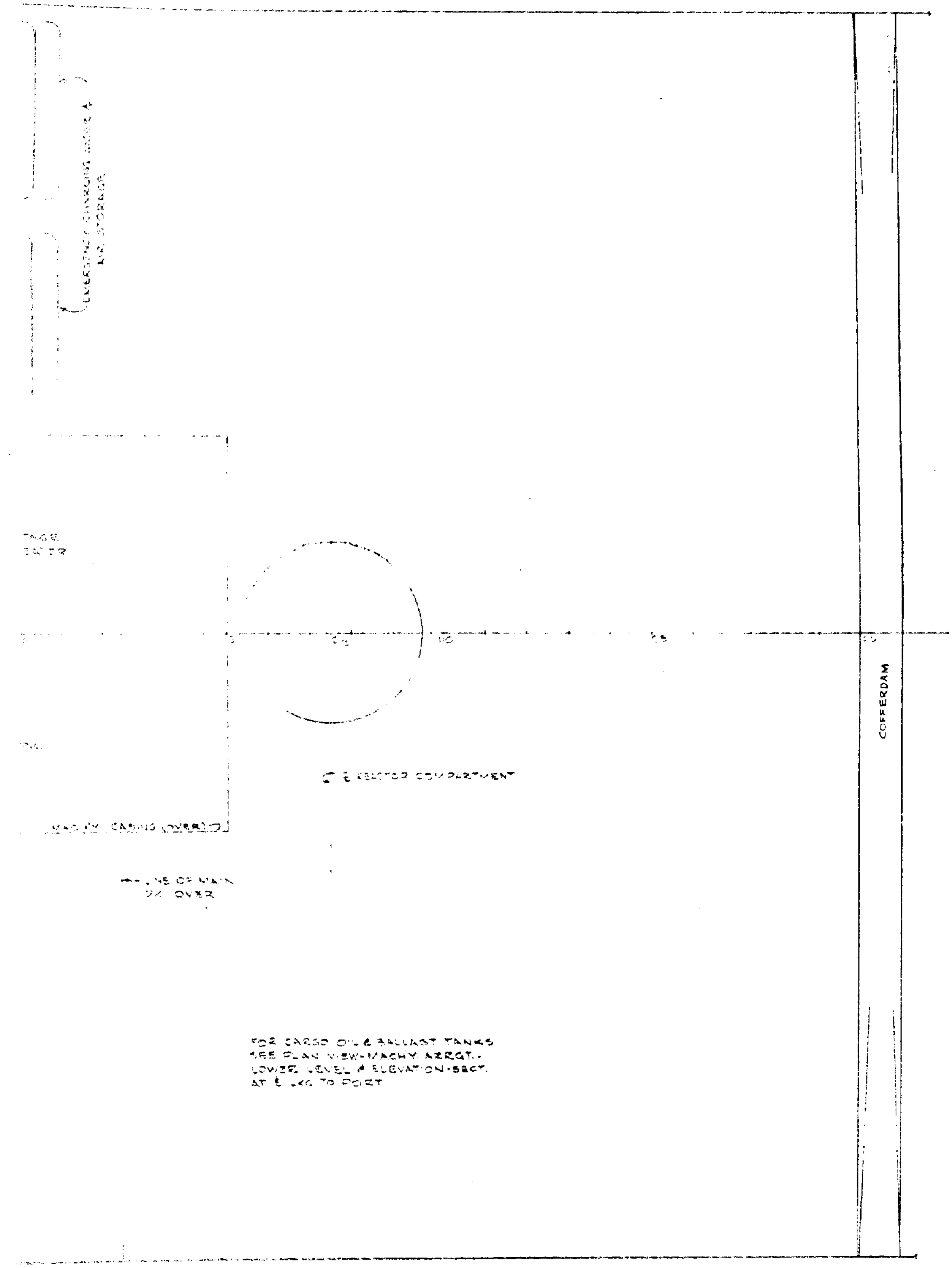
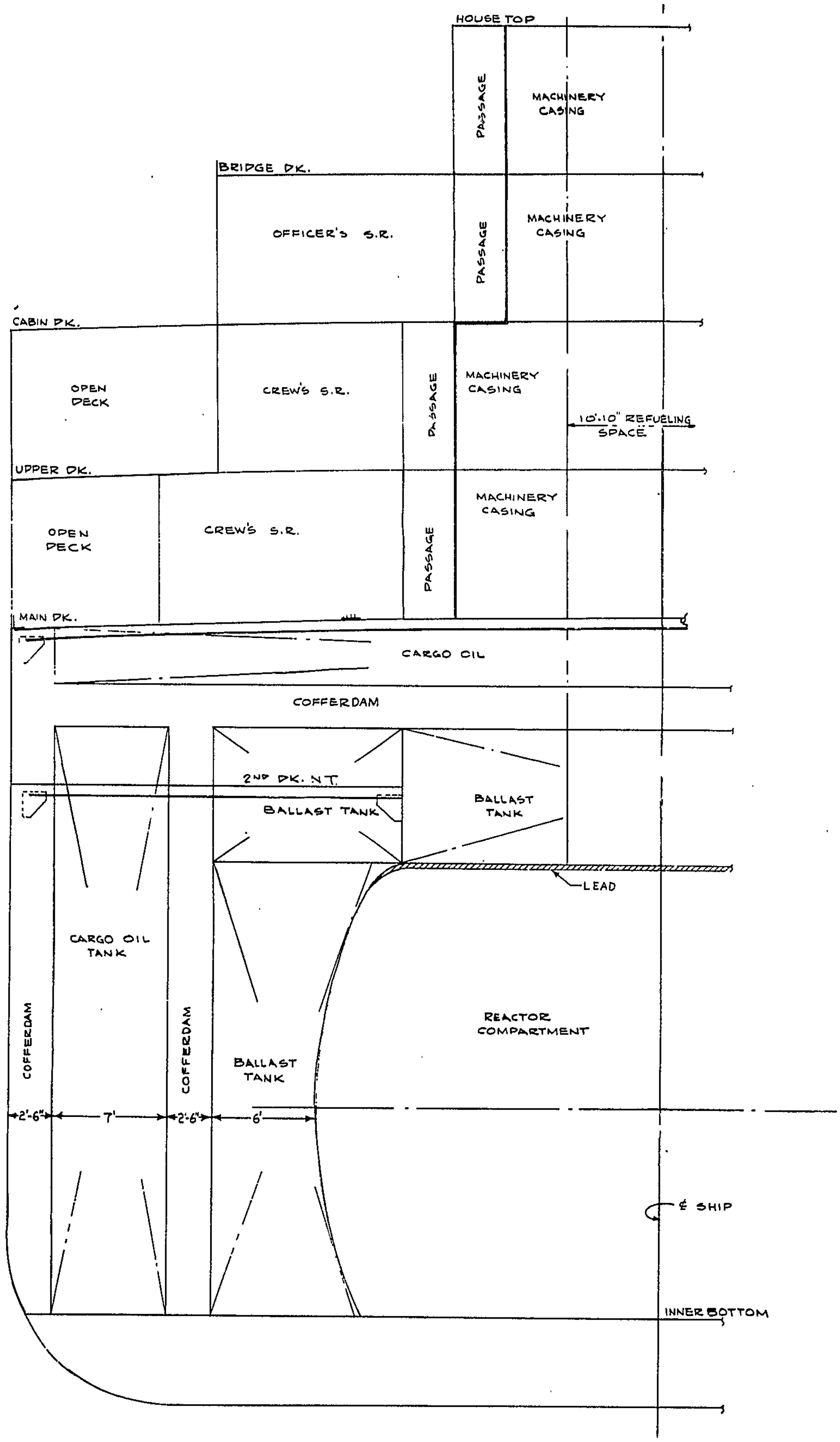

COFFERDAM
FOR CARGO OIL & BALLAST TANKS
SEE PLAN VIEW-MACHY ARRGT.-
LOWER LEVEL & ELEVATION-SECT.
AT ℄ LKG TO PORT

FIG NO 9



SECTION AT FR. 112½
LKG. AFT.
STBD. SIDE SHOWN - PORT SIM.

FIG. NO. 10

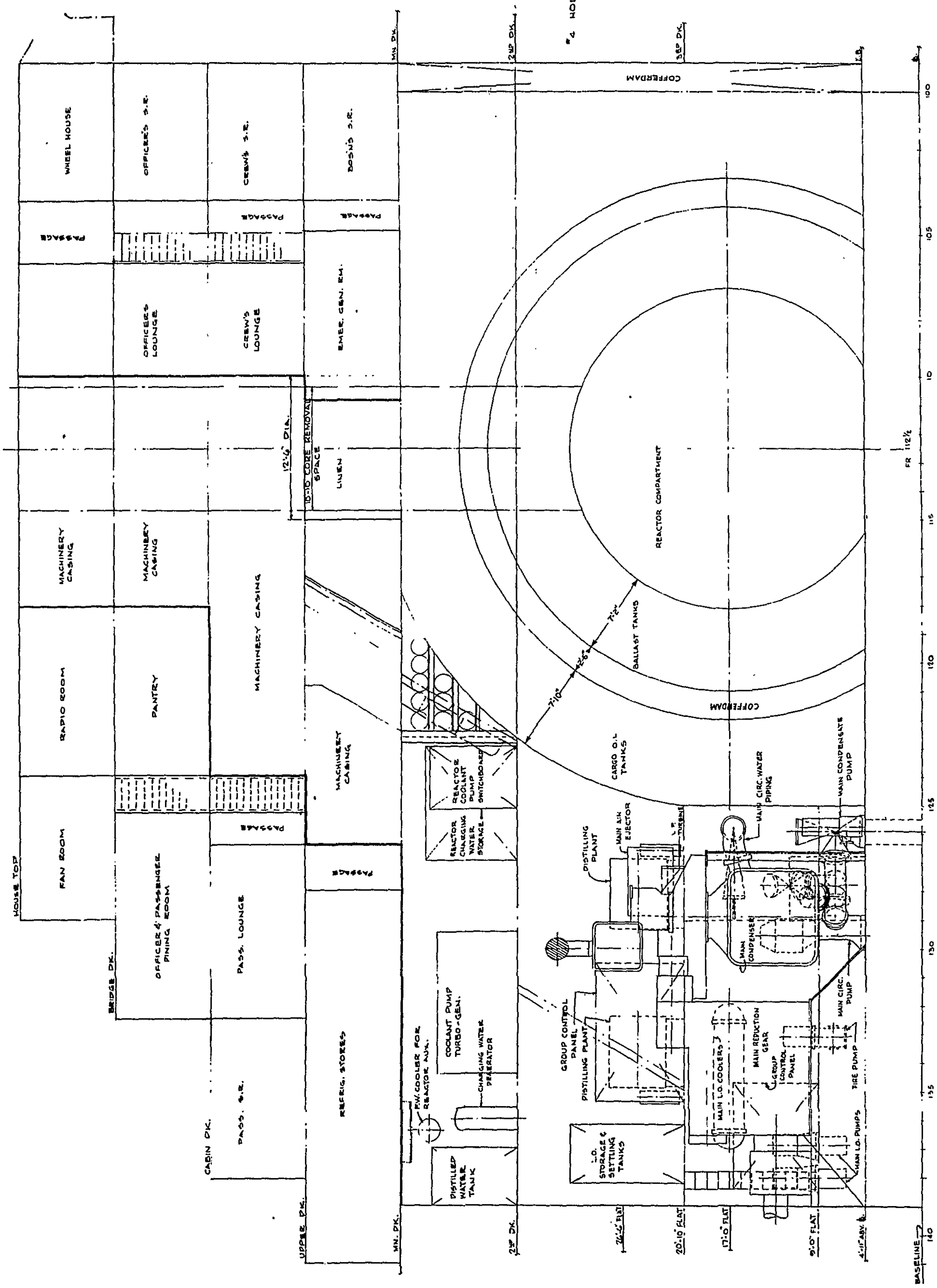
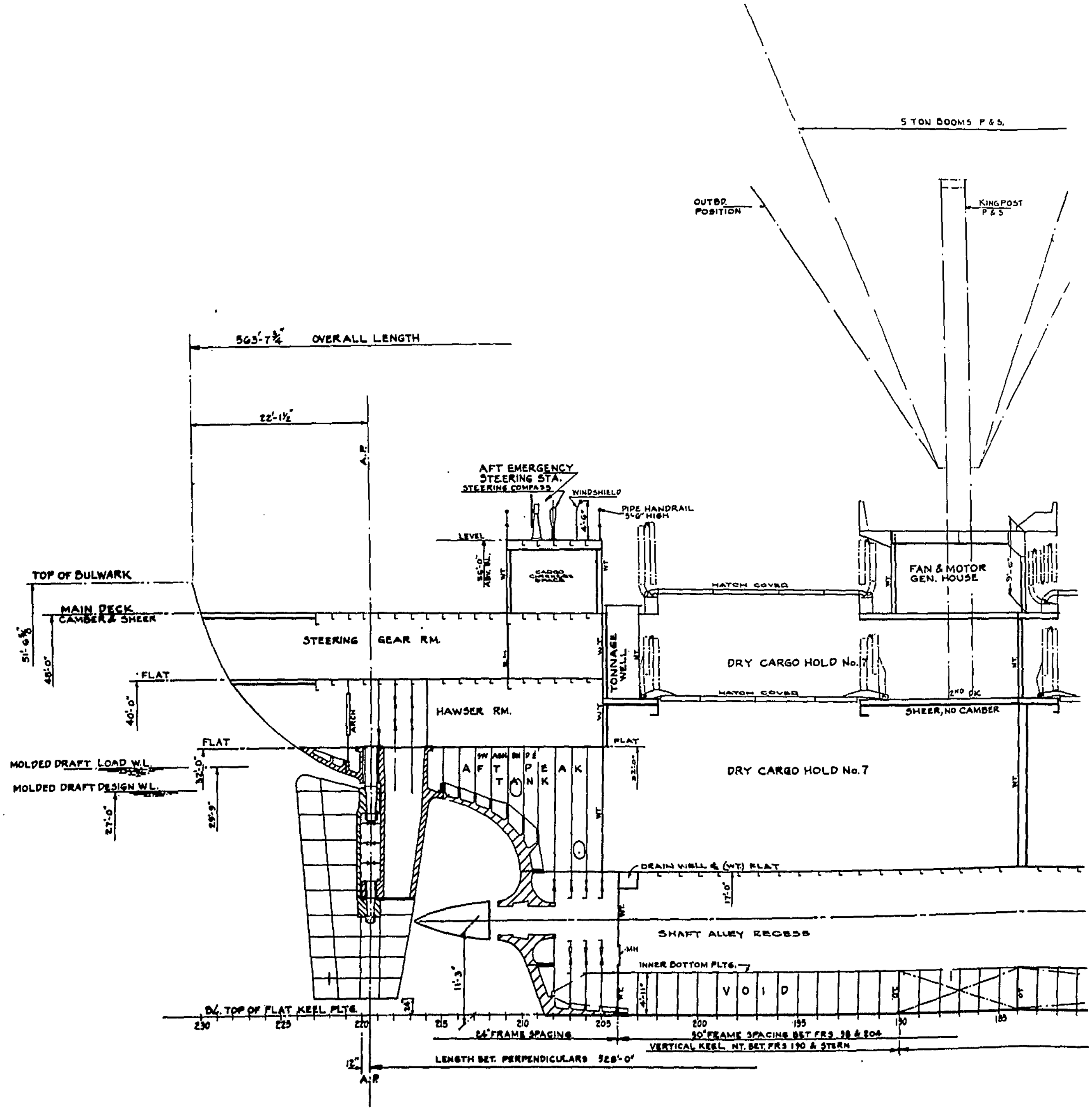
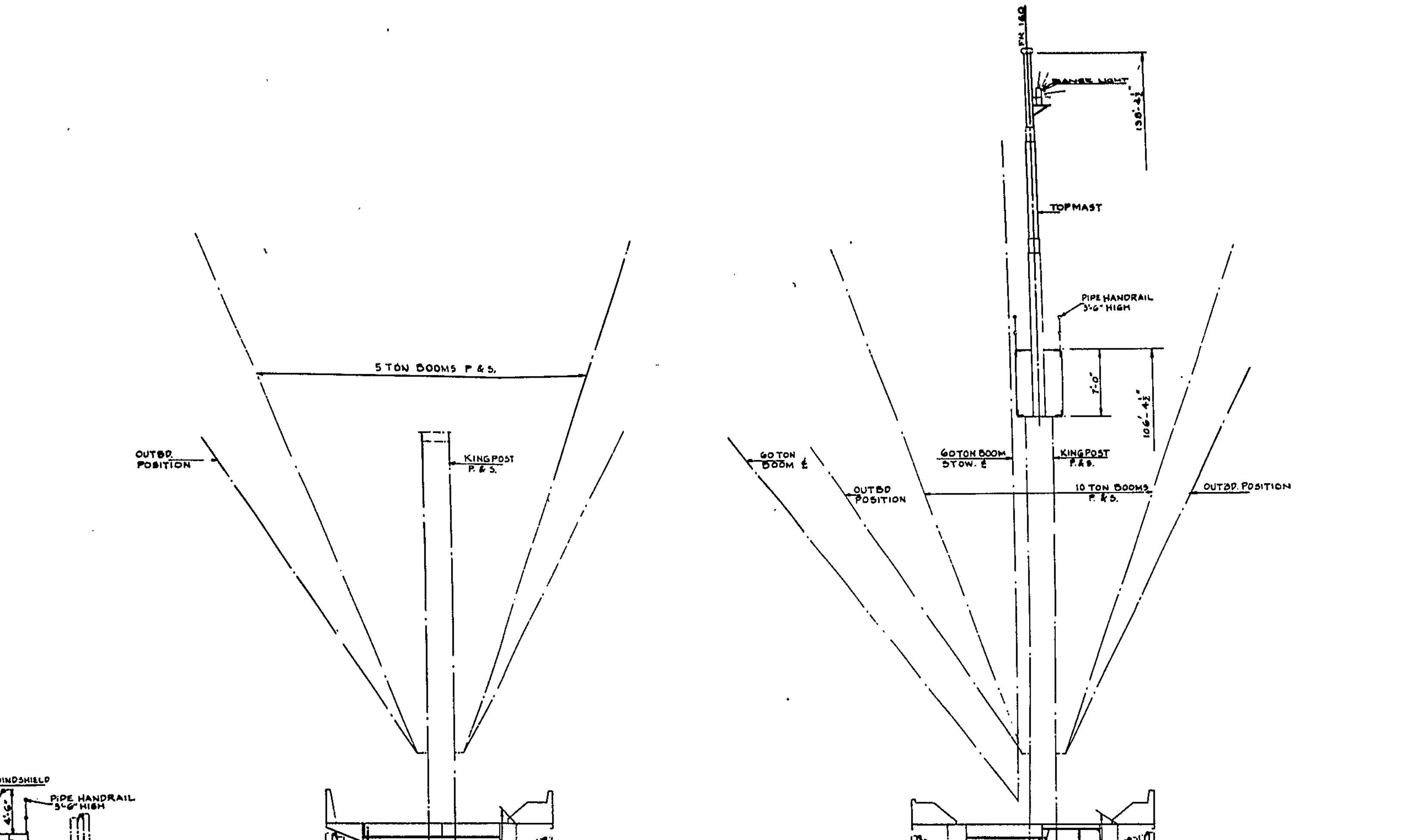


FIG. NO. 11

ELEVATION
¢ SHIP - LKG. TO PORT



5 TON BOOMS P & S.
OUTBD POSITION
KINGPOST P & S
563'-7¾" OVERALL LENGTH
22'-1½"
A.P.
AFT EMERGENCY STEERING STA.
STEERING COMPASS
WINDSHIELD
PIPE HANDRAIL 3'-6" HIGH
LEVEL
FAN & MOTOR GEN. HOUSE
TOP OF BULWARK
MAIN DECK
CAMBER & SHEER
HATCH COVER
STEERING GEAR RM.
TONNAGE WELL
DRY CARGO HOLD No.
FLAT
HAWSER RM.
2ND DK
SHEER, NO CAMBER
MOLDED DRAFT LOAD W.L.
MOLDED DRAFT DESIGN W.L.
AFT PEAK TANK
DRY CARGO HOLD No. 7
DRAIN WELL & (WT) FLAT
SHAFT ALLEY RECESS
INNER BOTTOM PLTS.
V O I D
B/L TOP OF FLAT KEEL PLTS.
24" FRAME SPACING
30" FRAME SPACING BET FRS 38 & 204
VERTICAL KEEL NT. BET. FRS 190 & STERN
LENGTH BET. PERPENDICULARS 528'-0"
A.P.


5 TON BOOMS P & S.
OUTBD. POSITION
KINGPOST P. & S.
60 TON BOOM ℄
OUTBD POSITION
60 TON BOOM STOW. ℄
KINGPOST P. & S.
10 TON BOOMS P. & S.
OUTBD. POSITION
TOPMAST
PIPE HANDRAIL 3'-6" HIGH
PIPE HANDRAIL 3'-6" HIGH
HATCH COVER
FAN & MOTOR GEN. HOUSE
FAN & MOTOR GEN. HOUSE
PASS.
TONNAGE WELL
DRY CARGO HOLD No. 7
DRY CARGO HOLD No. 6
DRY CARGO HOLD No. 5
SHEER, NO CAMBER
2ND DK
TRUNK(S)
INSUL. DR.
REFRIG. CARGO HOLD No. 5
DRY CARGO HOLD No. 7
DRY CARGO HOLD No. 6
DRAIN WELL & (WT.) FLAT
℄ OF SHAFT
SHAFT ALLEY RECESS
SHAFT ALLEY
DRAIN WELL ℄ (WT)
INNER BOTTOM PLTS.
V O I D
B A L L A S T P. & S.
30" FRAME SPACING BET. FRS. 38 & 204
VERTICAL KEEL NT. BET. FRS 190 & STERN
VERTICAL KEEL OT. BET. FRS. 160 & 190
VERTICAL KEEL NT. BET. FRS. 37 & 160
205
200
195
190
185
180
175
170
165
160
155
150
145

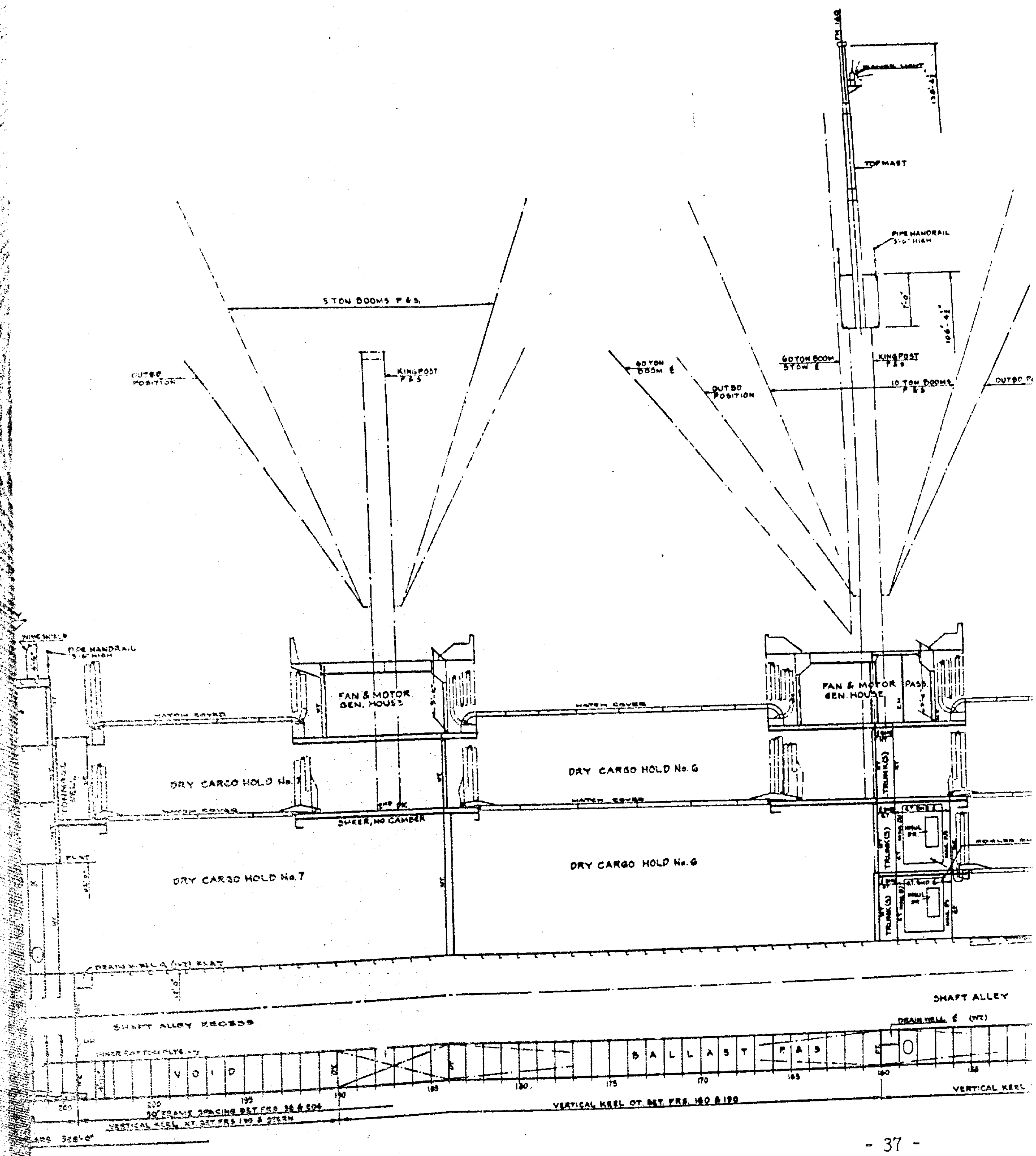
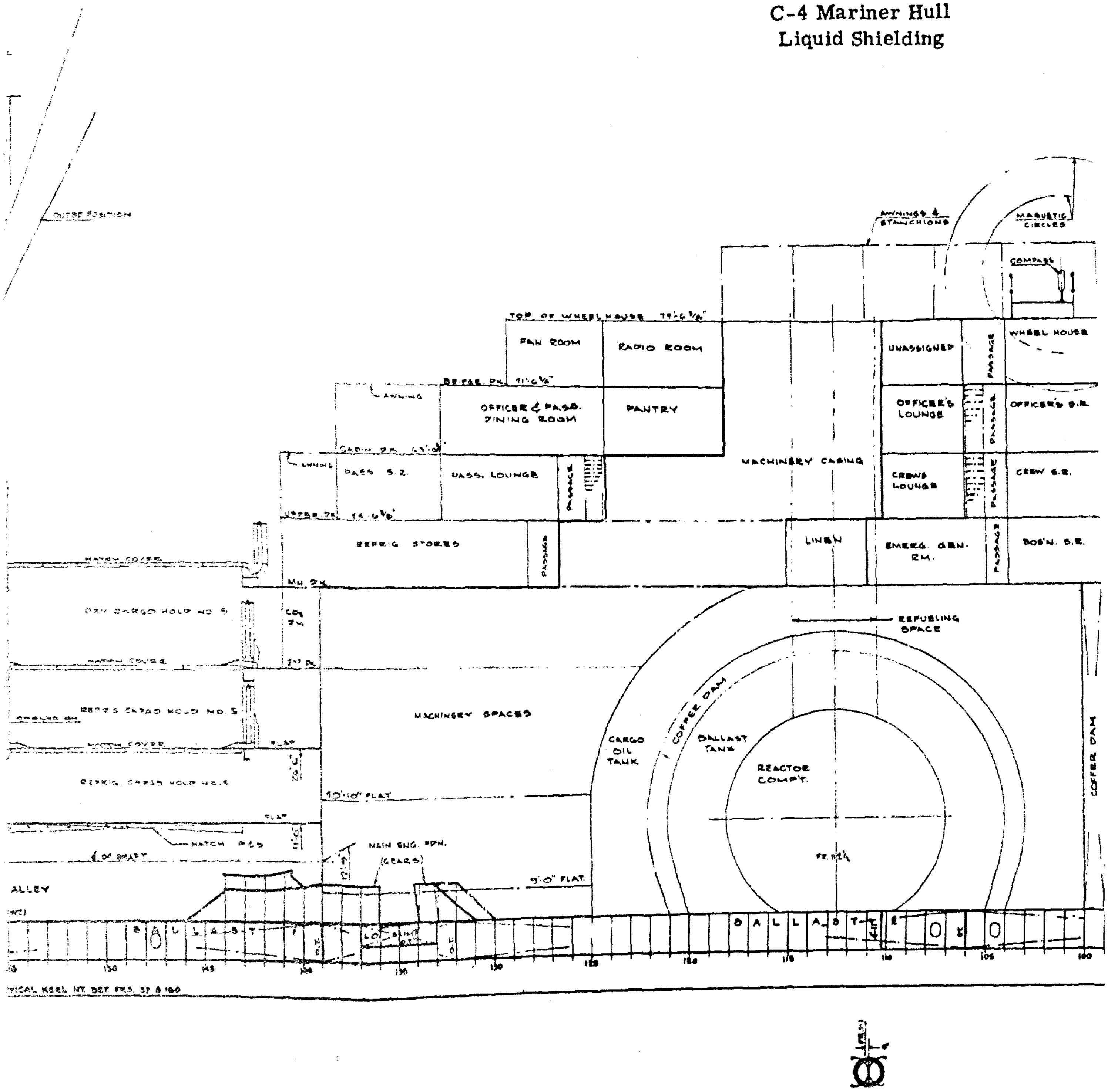
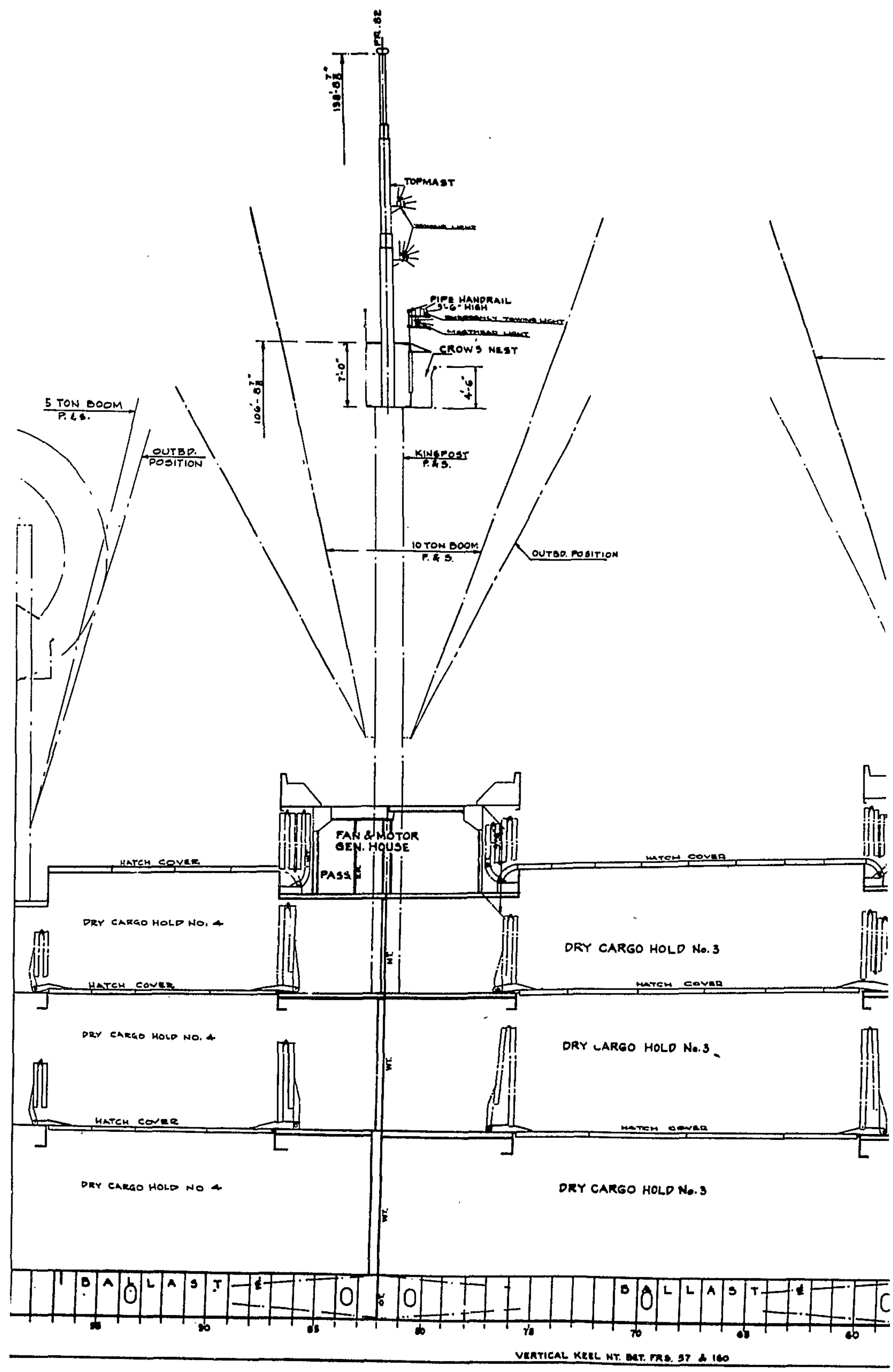

5 TON BOOMS P & S.
KINGPOST P & S
OUTBD POSITION
TOPMAST
PIPE HANDRAIL
60 TON BOOM ℄
60 TON BOOM STOW ℄
OUTBD POSITION
10 TON BOOMS P & S
FAN & MOTOR GEN. HOUSE
FAN & MOTOR GEN. HOUSE
HATCH COVER
DRY CARGO HOLD No. 7
DRY CARGO HOLD No. 6
SHEER, NO CAMBER
DRY CARGO HOLD No. 7
DRY CARGO HOLD No. 6
SHAFT ALLEY
SHAFT ALLEY RECESS
B A L L A S T
V O I D
VERTICAL KEEL

FIG. NO. 13
INBOARD PROFILE
Nuclear Powered Merchant Ship
C-4 Mariner Hull
Liquid Shielding



(See back of this page for continuation of this drawing.)

(See back of this page for continuation of this drawing.)



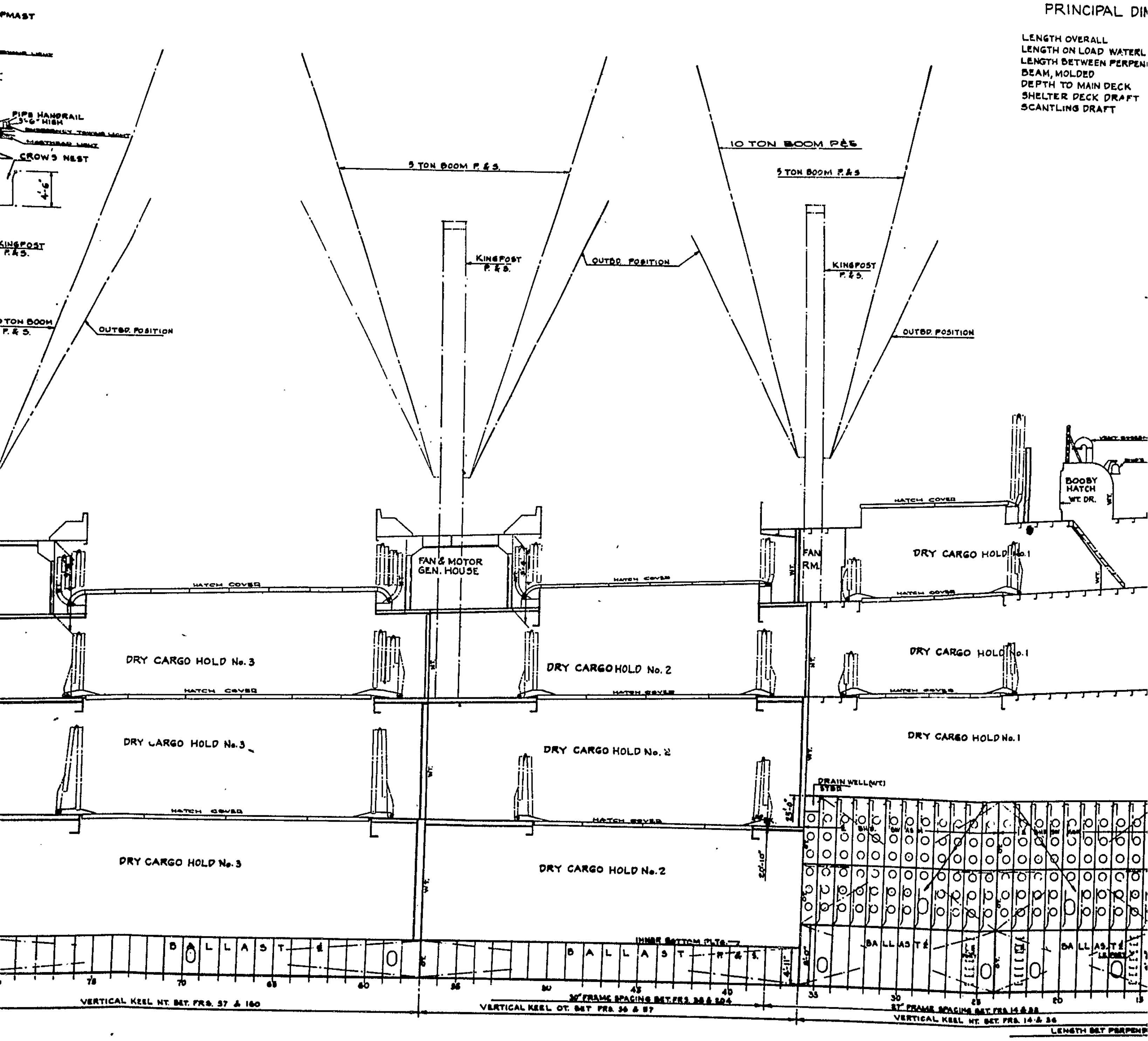
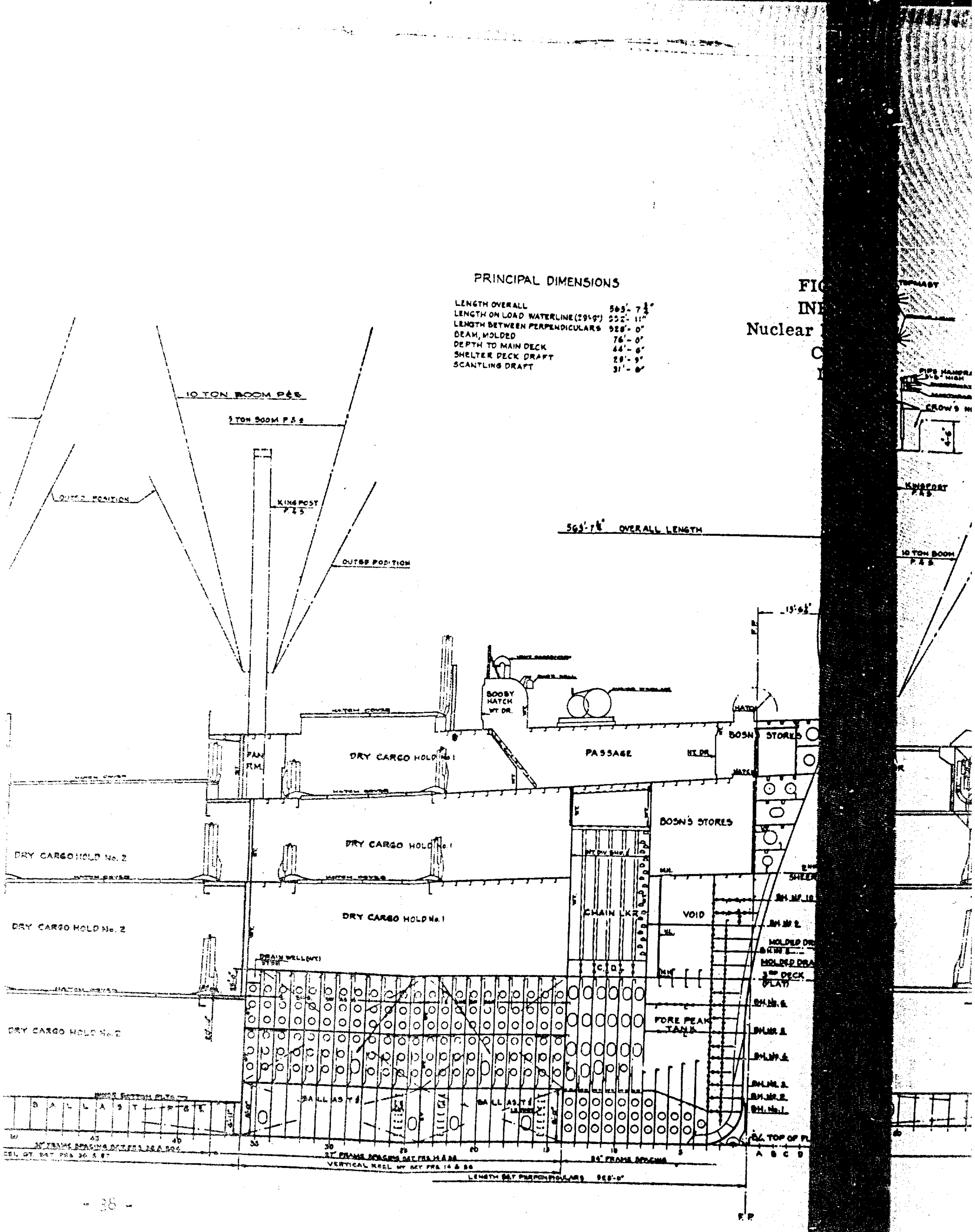

PRINCIPAL DIM
LENGTH OVERALL
LENGTH ON LOAD WATERL
LENGTH BETWEEN PERPEN
BEAM, MOLDED
DEPTH TO MAIN DECK
SHELTER DECK DRAFT
SCANTLING DRAFT
PIPE HANDRAIL 3'-6" HIGH
CROWS NEST
KINGPOST F. & S.
TON BOOM F. & S.
OUTBD. POSITION
5 TON BOOM F. & S.
KINGPOST F. & S.
OUTBD. POSITION
10 TON BOOM P.& S.
5 TON BOOM F. & S
KINGPOST F. & S.
OUTBD. POSITION
BOOBY HATCH WT. DR.
FAN & MOTOR GEN. HOUSE
FAN RM.
HATCH COVER
DRY CARGO HOLD No. 1
DRY CARGO HOLD No. 3
DRY CARGO HOLD No. 2
DRY CARGO HOLD No. 1
DRY CARGO HOLD No. 3
DRY CARGO HOLD No. 2
DRY CARGO HOLD No. 1
DRAIN WELL (W.T.)
DRY CARGO HOLD No. 3
DRY CARGO HOLD No. 2
BALLAST
INNER BOTTOM PLTG.
BALLAST
BALLAST
VERTICAL KEEL NT. BET. FRS. 57 & 160
30" FRAME SPACING BET. FRS. 36 & 104
VERTICAL KEEL OT. BET. FRS. 36 & 57
27" FRAME SPACING BET. FRS. 14 & 36
VERTICAL KEEL NT. BET. FRS. 14 & 36
LENGTH BET. PERPEN

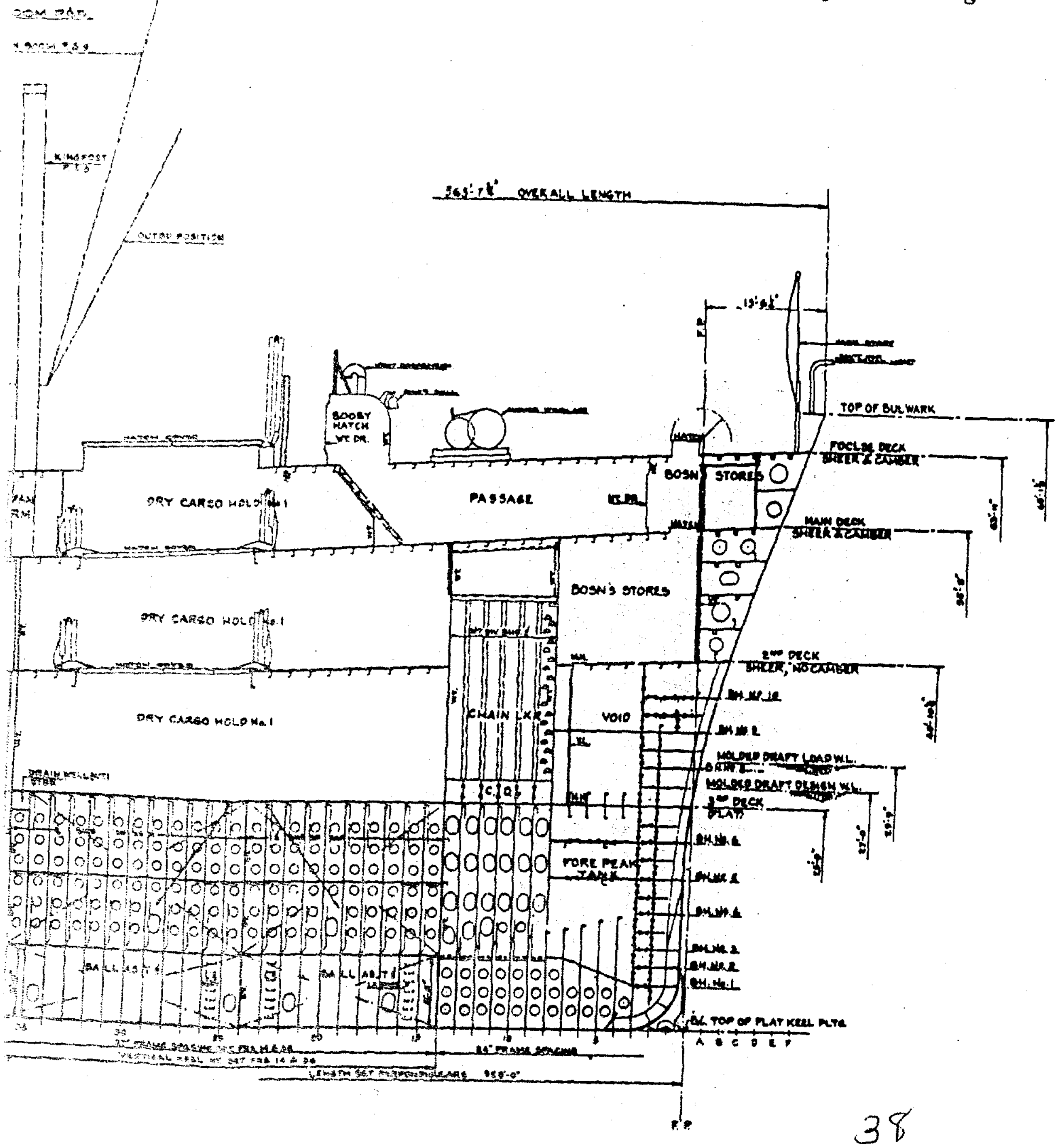
FIG
INE
Nuclear
C
I

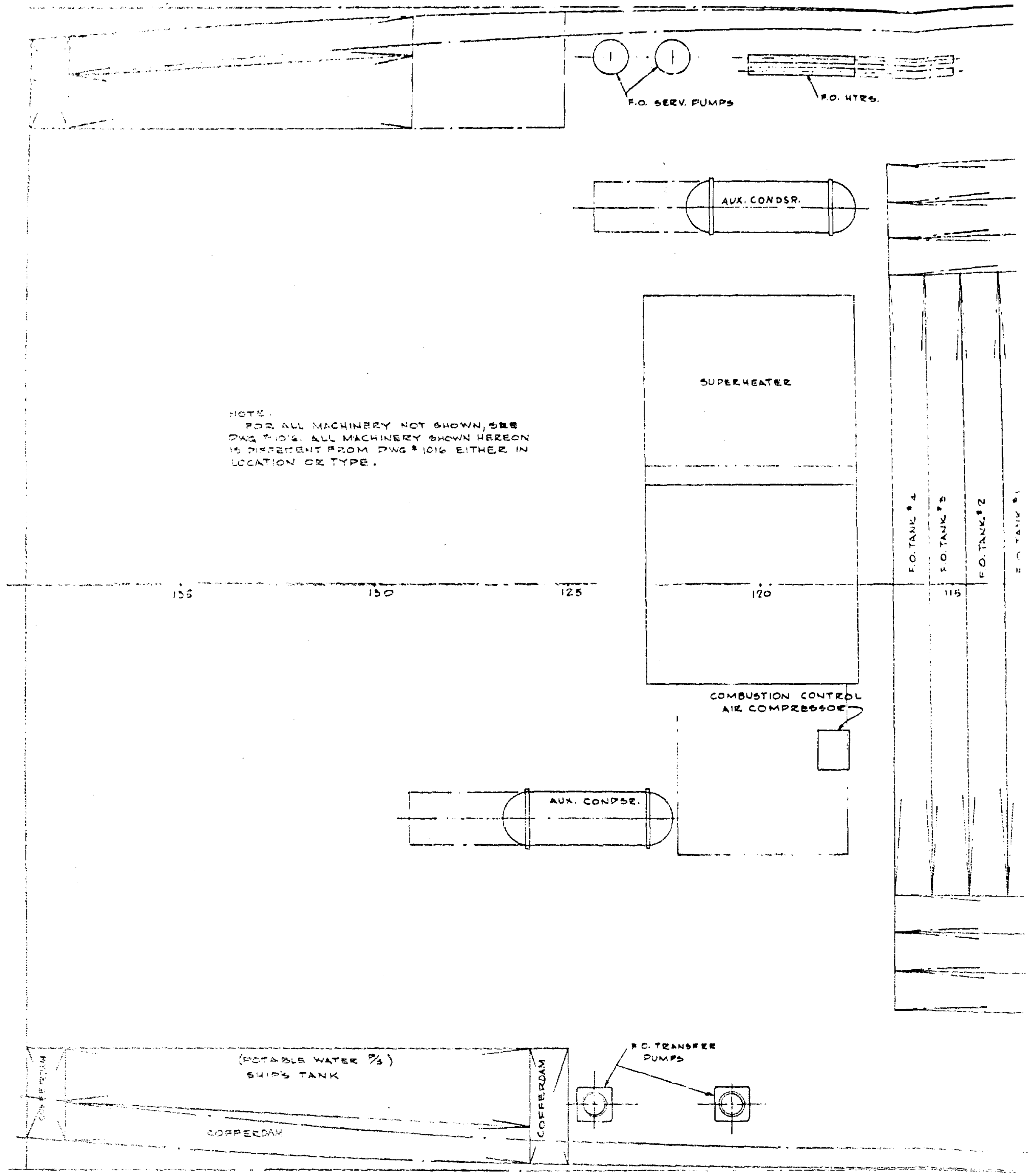


PRINCIPAL DIMENSIONS

LENGTH OVERALL	563'- 7¾"
LENGTH ON LOAD WATERLINE (29'-9")	552'- 11"
LENGTH BETWEEN PERPENDICULARS	528'- 0"
BEAM, MOLDED	76'- 0"
DEPTH TO MAIN DECK	44'- 6"
SHELTER DECK DRAFT	29'- 9"
SCANTLING DRAFT	31'- 6"

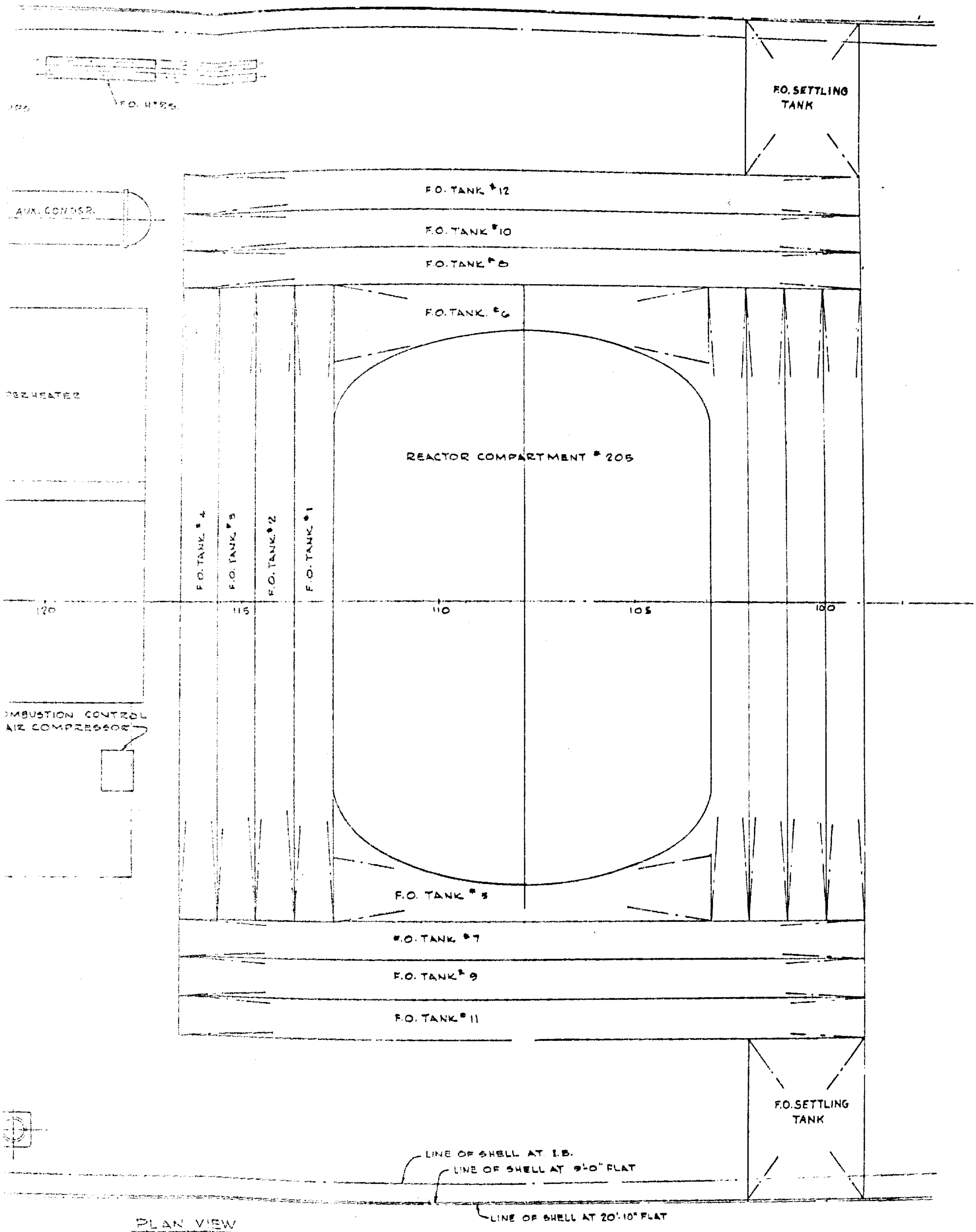
FIG. NO. 13 (cont'd.)
INBOARD PROFILE
Nuclear Powered Merchant Ship
C-4 Mariner Hull
Liquid Shielding





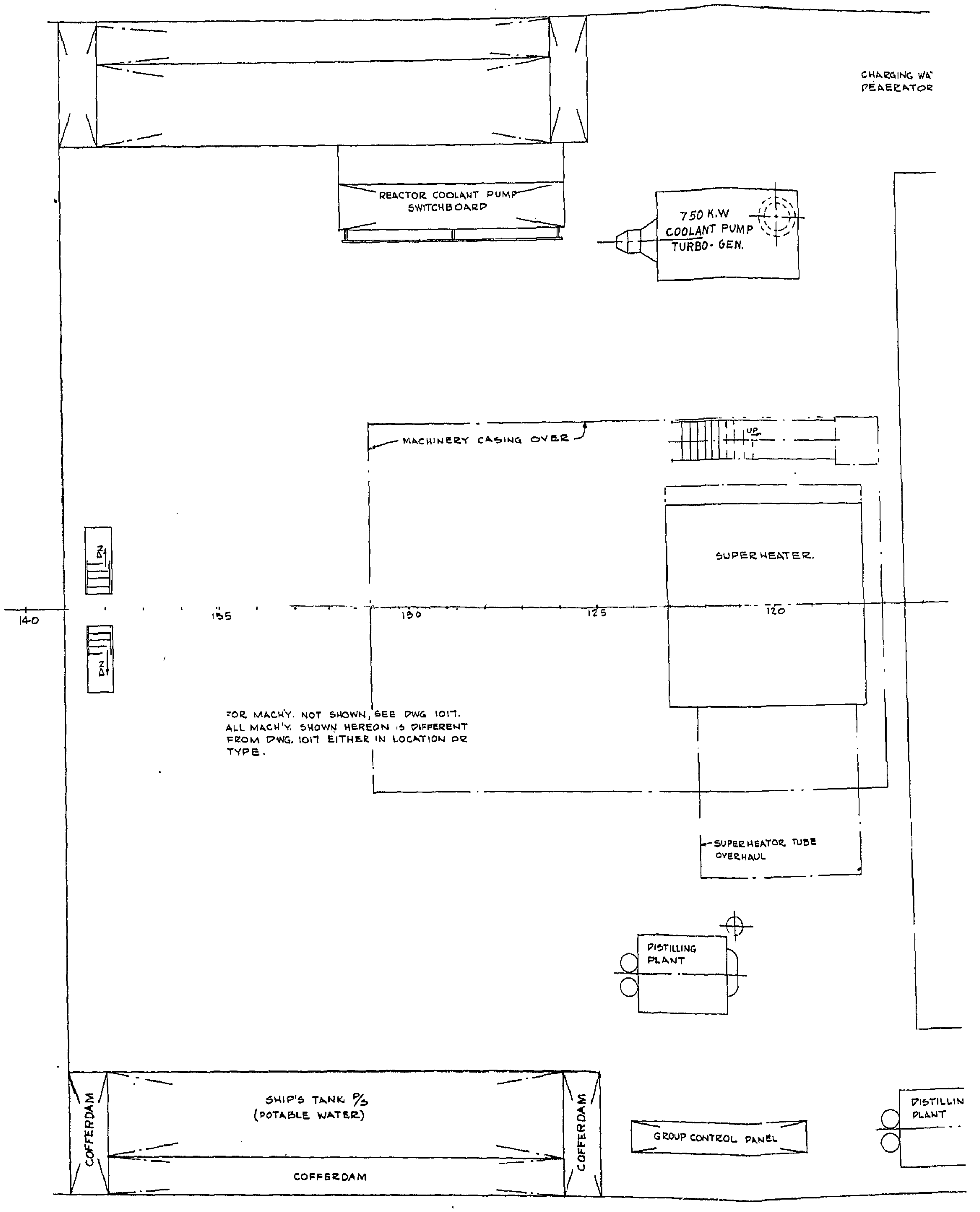
PLAN VIEW

MACHINERY ARRGT. - LOWER LEVEL

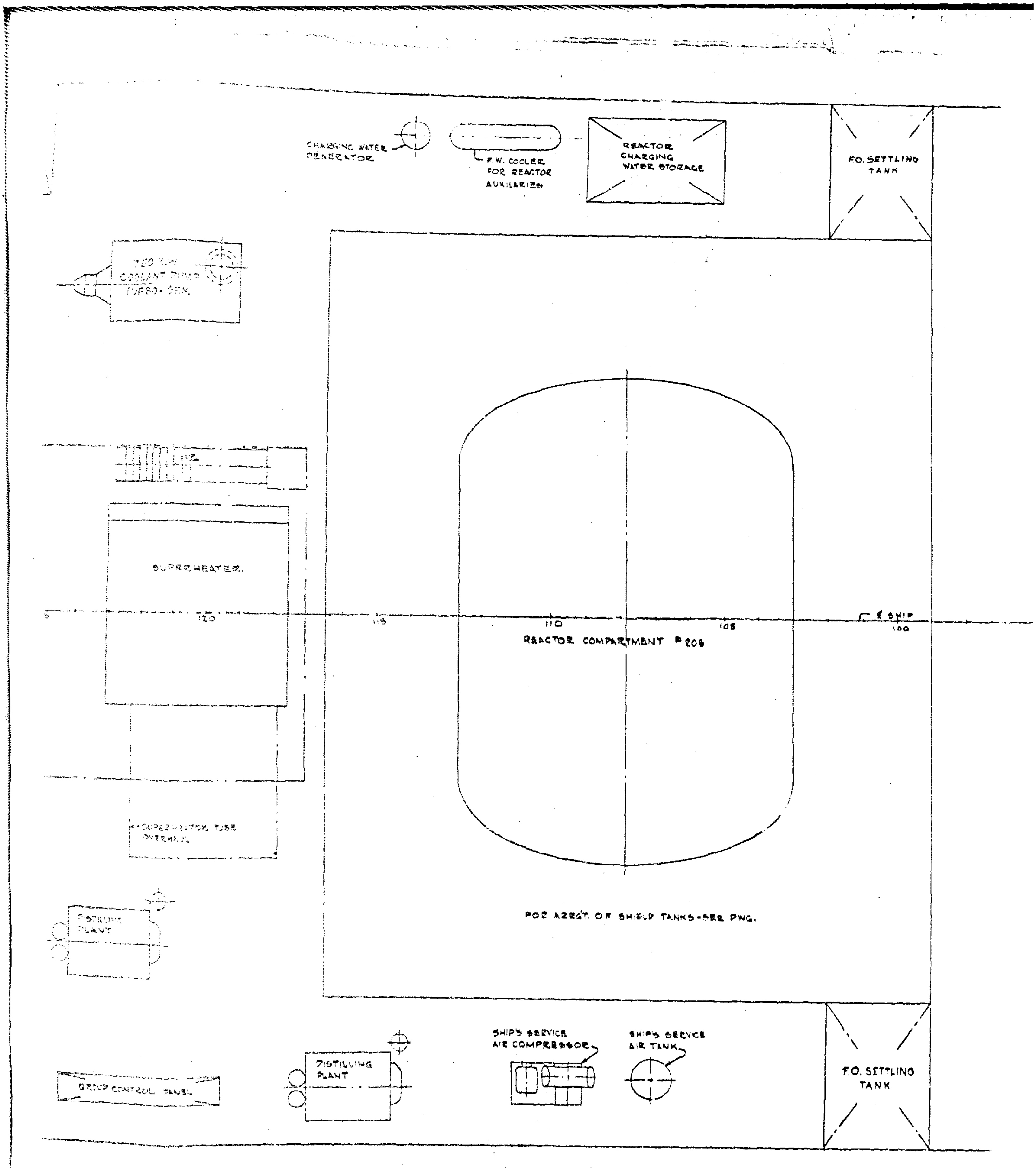


PLAN VIEW
MACHINERY ARRGT. - LOWER LEVEL

FIG. NO. 14

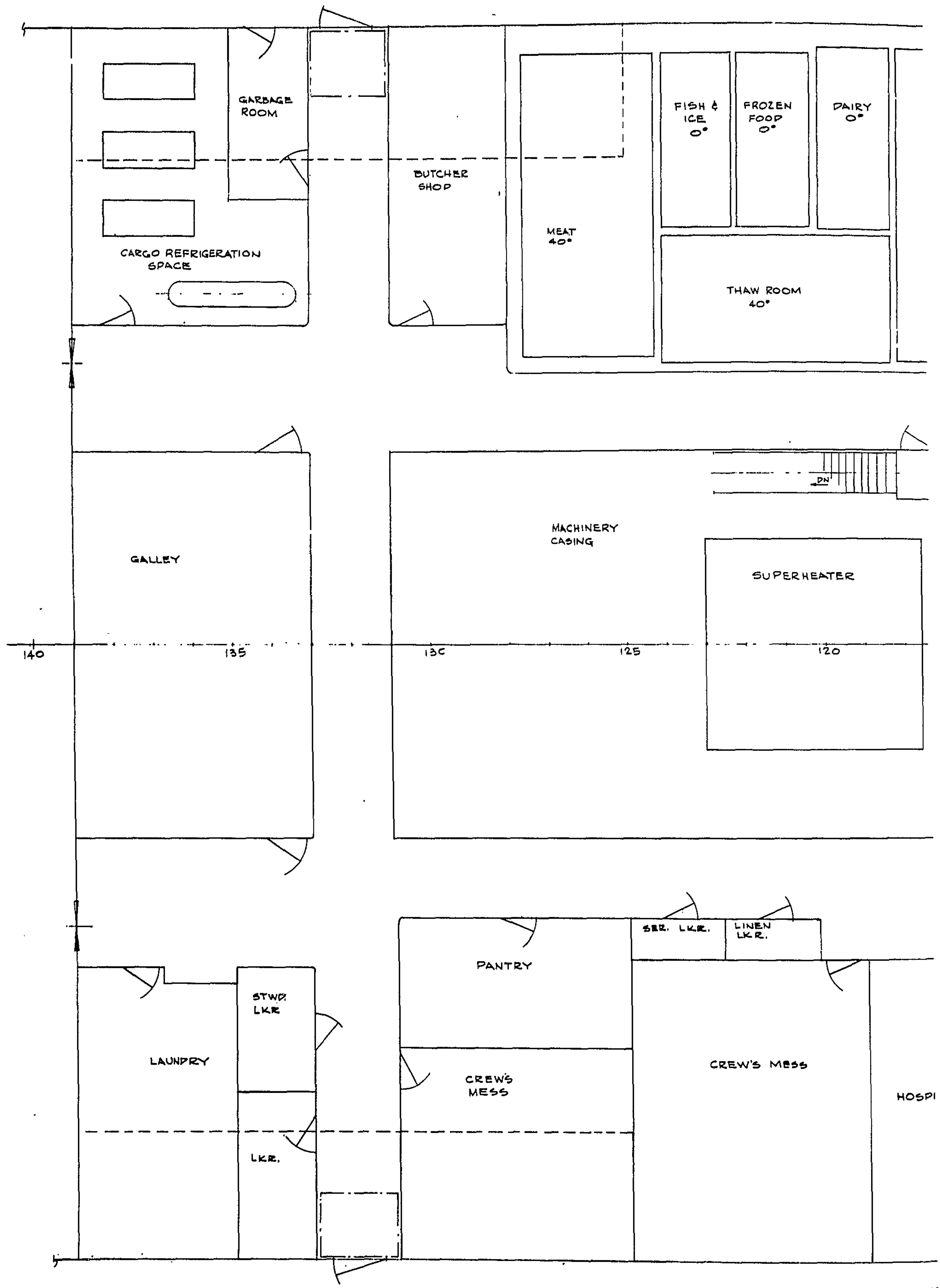


PLAN VIEW
MACHINERY ARRGT. - UPPER LEVEL
20'-10" AB. ℄

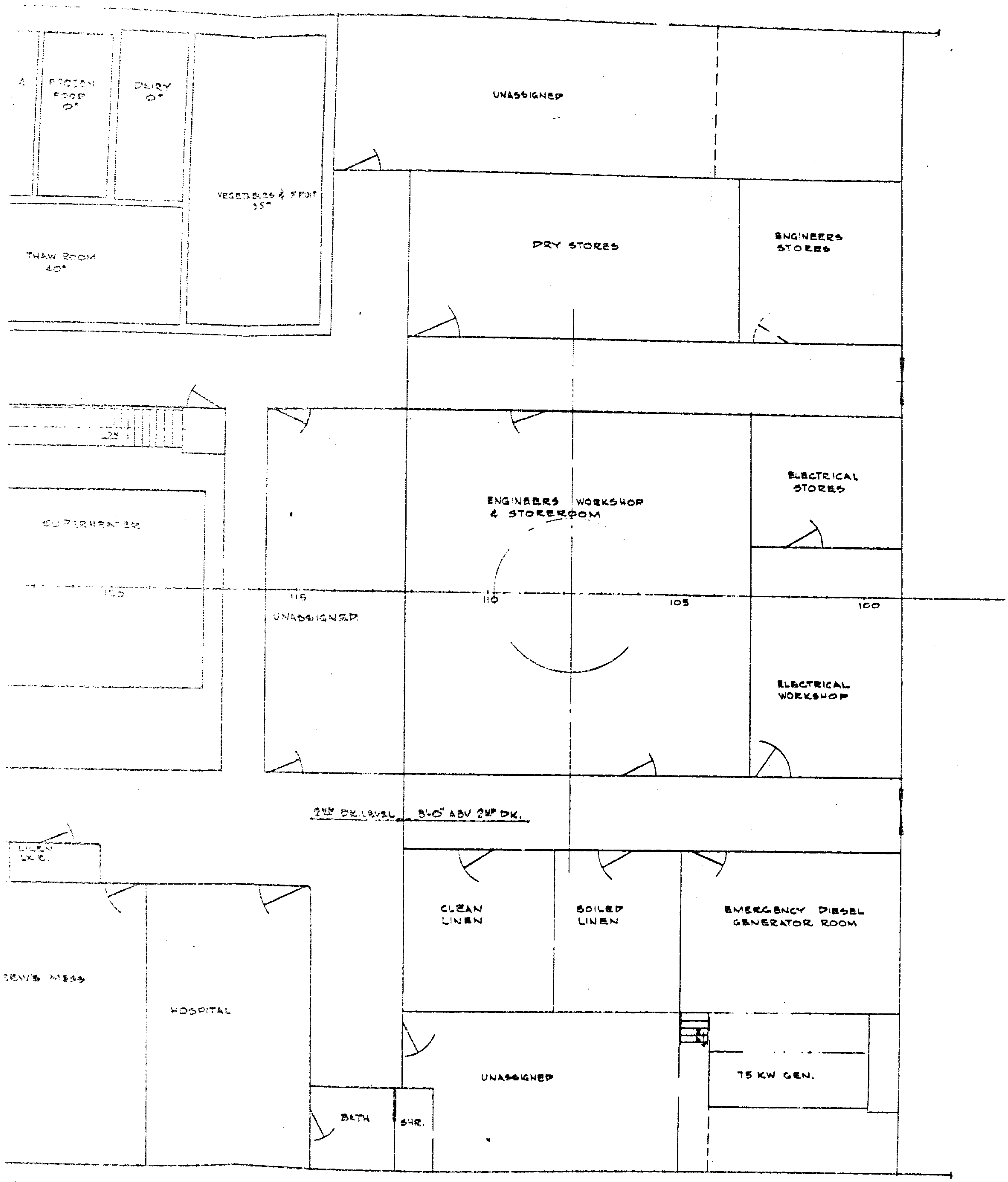


PLAN VIEW
MACHINERY ARRGT. - UPPER LEVEL
20'-10" AB/℄

FIG NO. 15

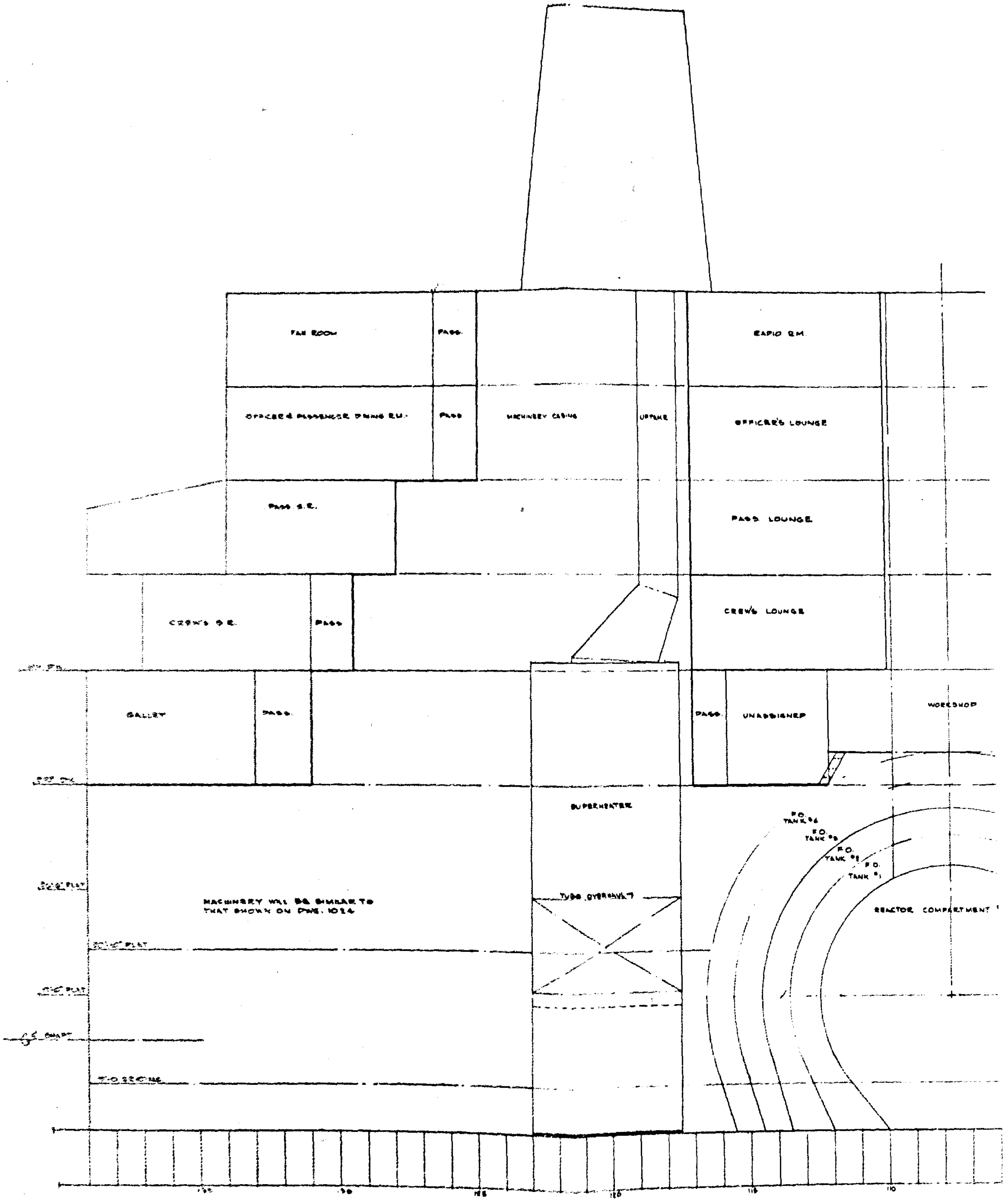


PLAN VI
2ND DECK AR



PLAN VIEW
2ND DECK ARRANGEMENT.

FIG. NO. 16



ELEVATION AT ℄
LKG. TO PORT

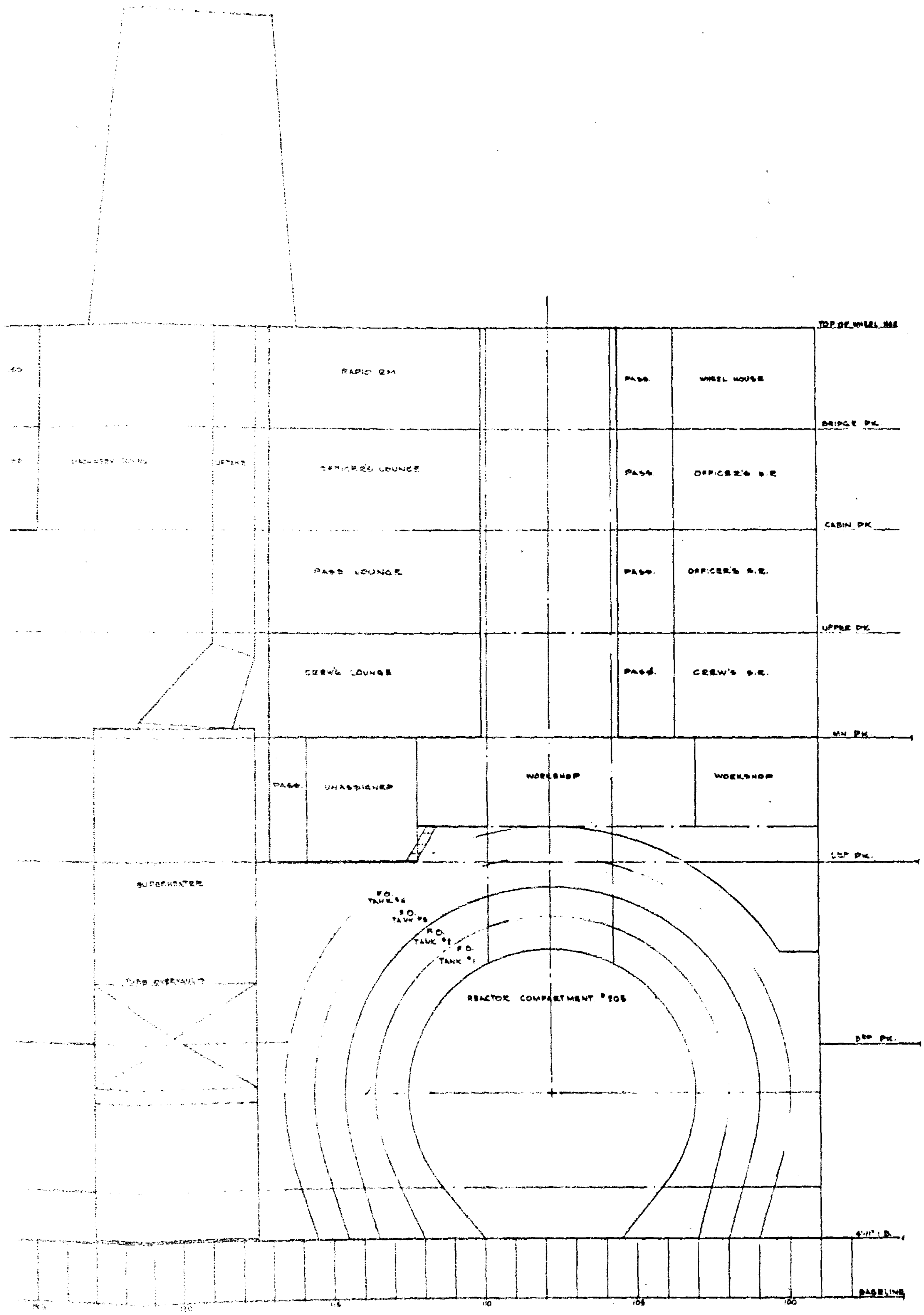
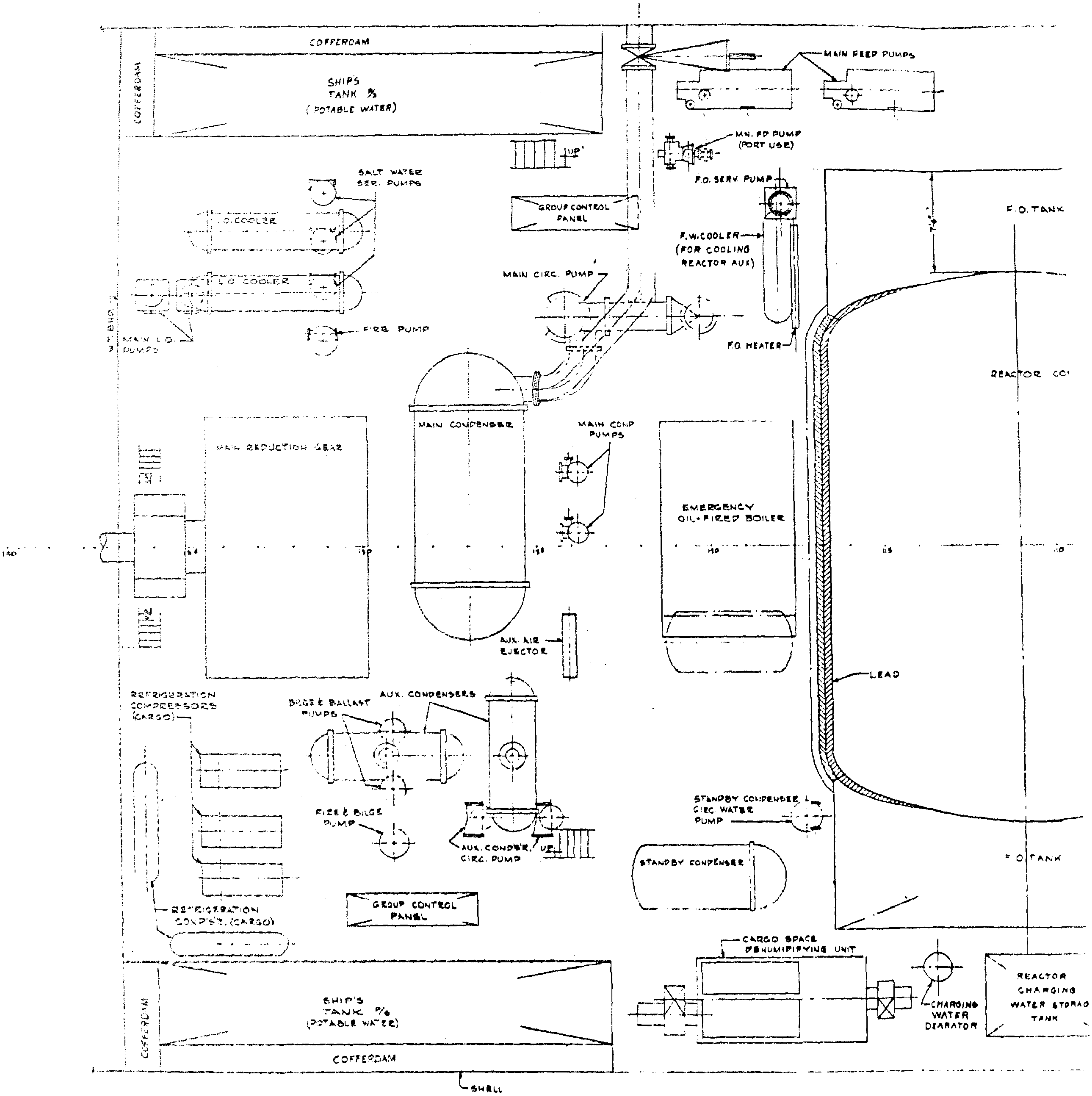
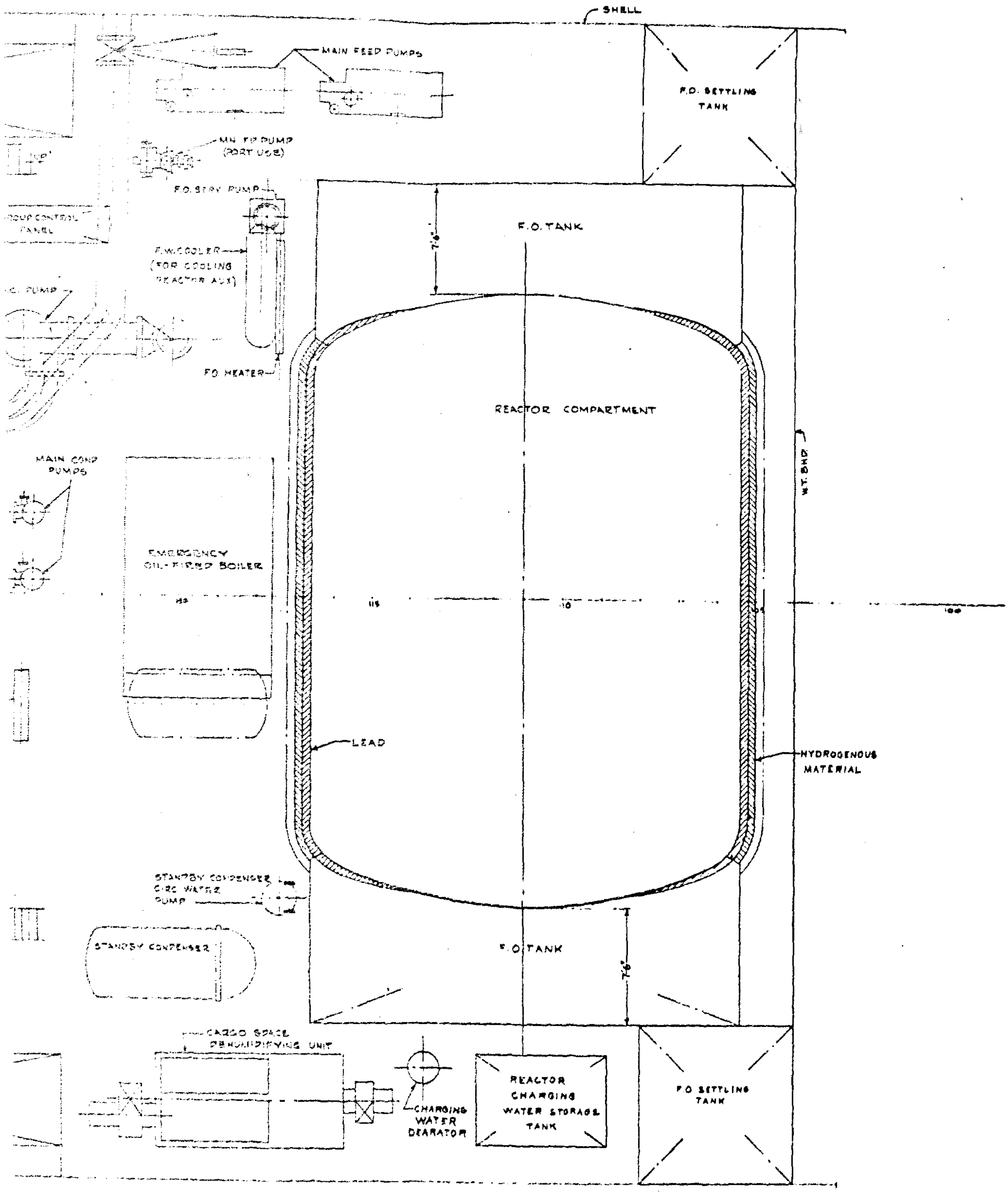


FIG NO. 17

ELEVATION AT ℄
TO PORT



PLAN VIEW - LOWER LEVEL
MACHINERY ARRGT.



PLAN VIEW - LOWER LEVEL
MACHINERY ARR'GT.

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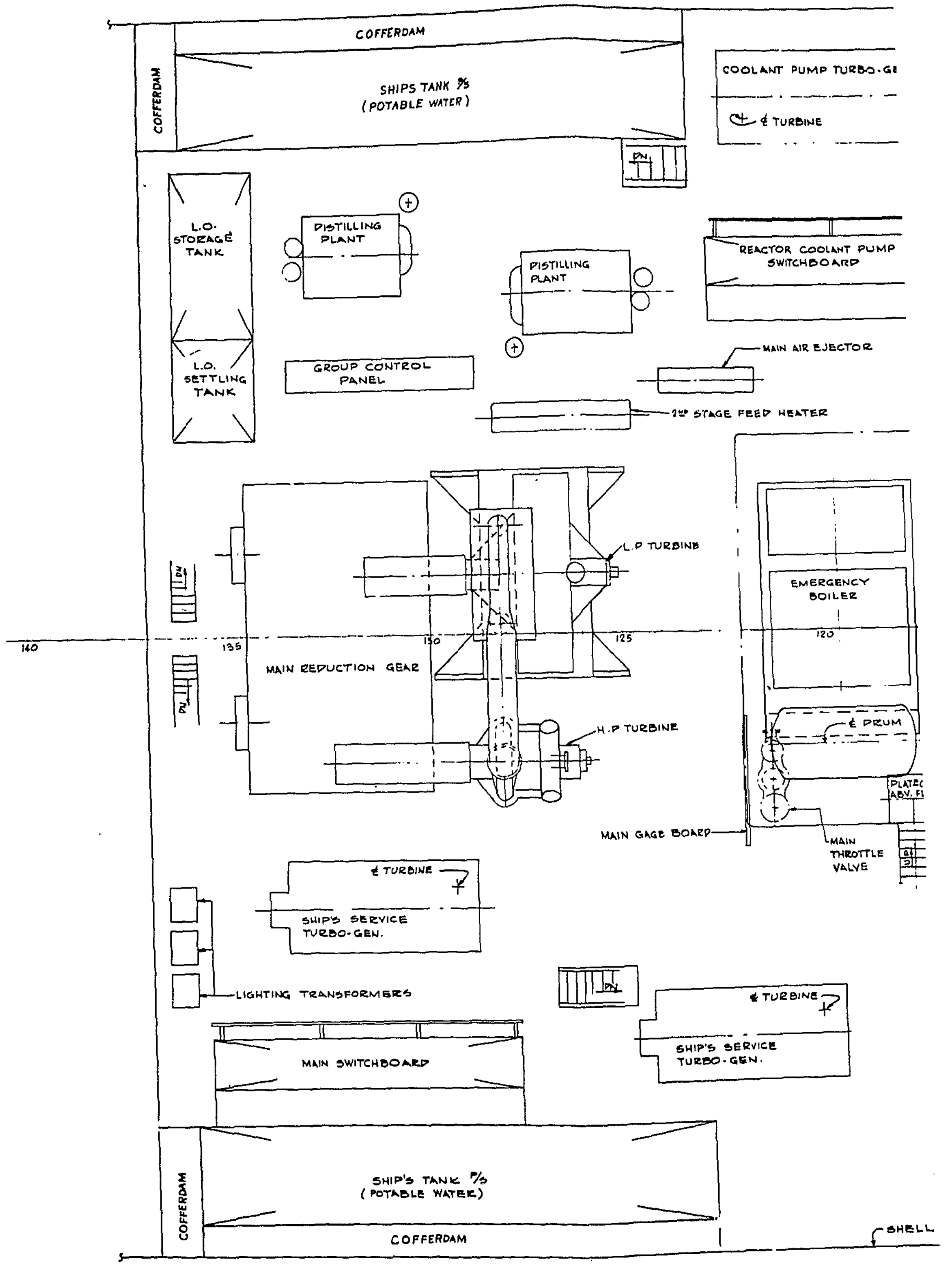
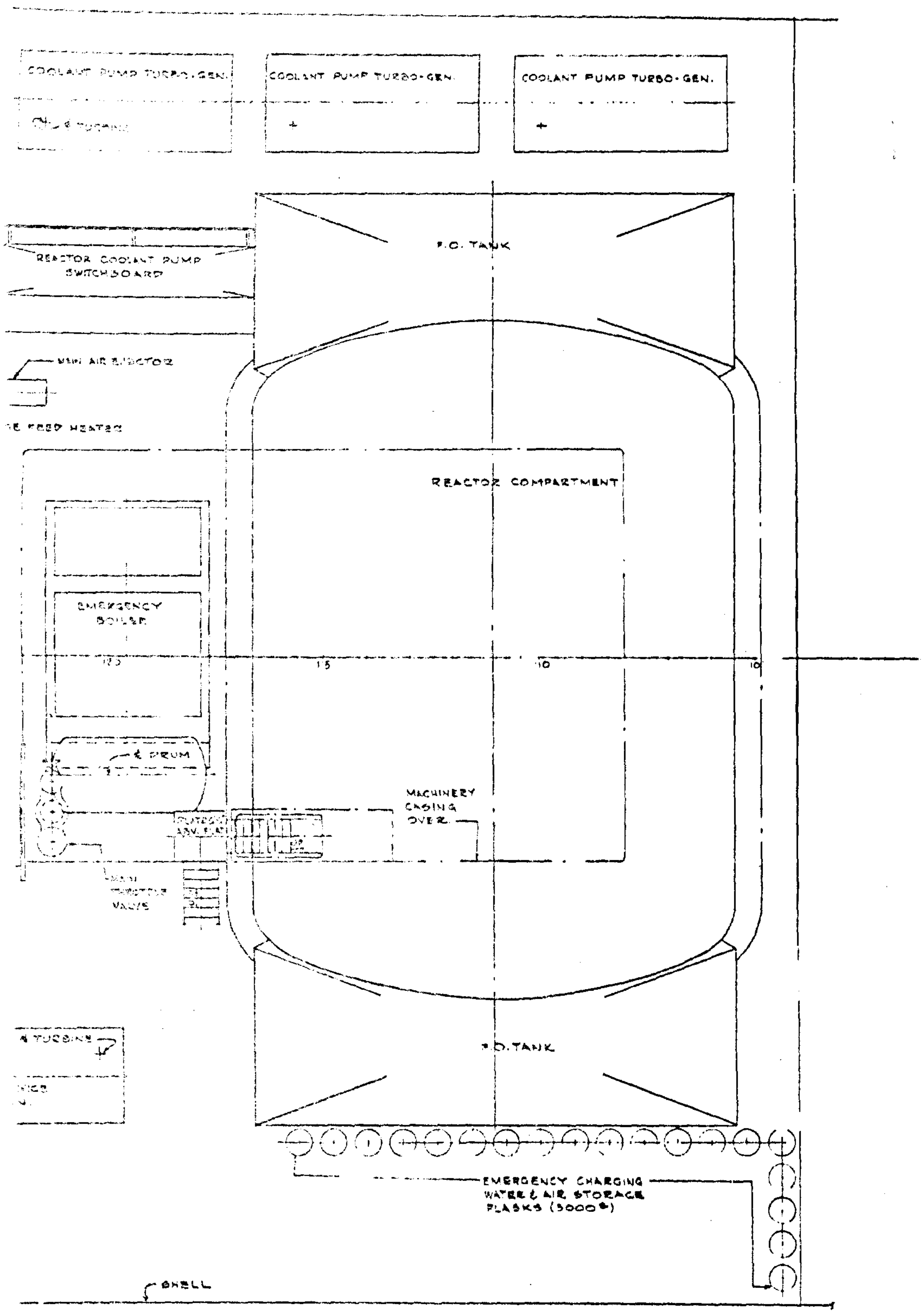
9-9-55

FIG NO. 18



PLAN VIEW - UPP
MACHINERY AR



PLAN VIEW - UPPER LEVEL
MACHINERY ARRGT.

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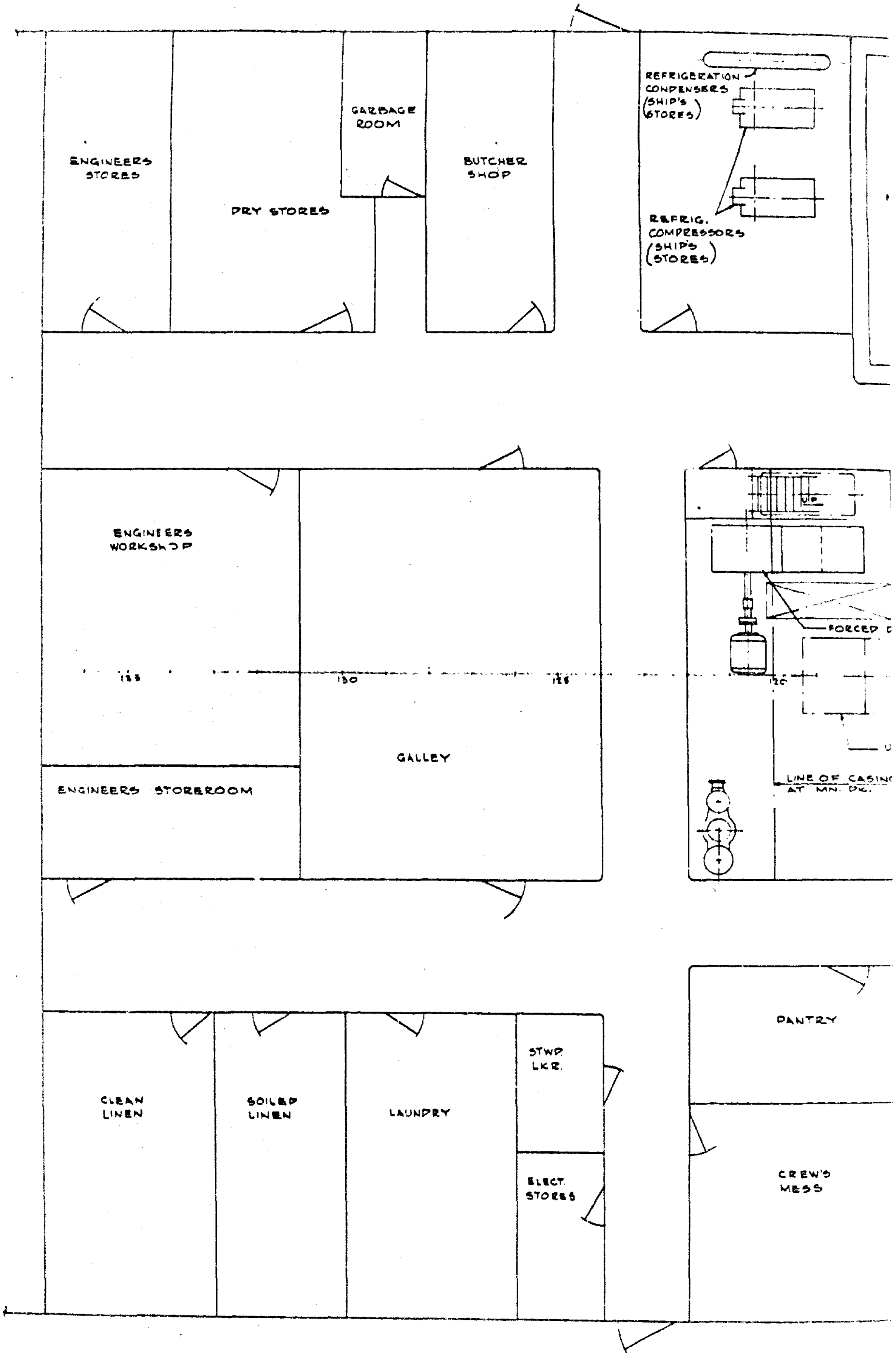
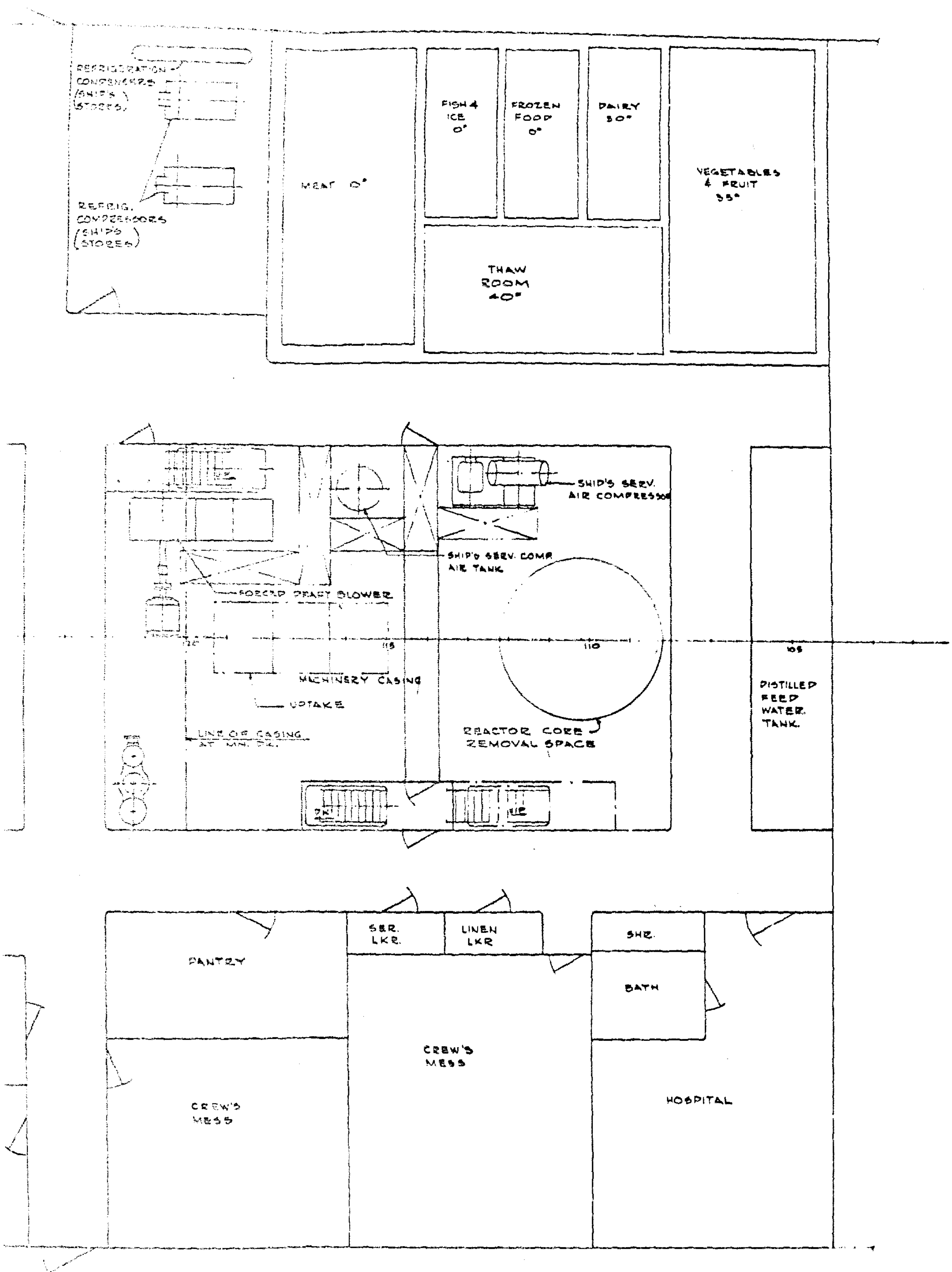
9-9-55

FIG. NO. 19


REFRIGERATION CONDENSERS (SHIP'S STORES)
ENGINEERS STORES
GARBAGE ROOM
DRY STORES
BUTCHER SHOP
REFRIG. COMPRESSORS (SHIP'S STORES)
ENGINEERS WORKSHOP
UP
FORCED
140
135
130
125
120
GALLEY
ENGINEERS STOREROOM
LINE OF
AT MN. DK.
PANTRY
CLEAN LINEN
SOILED LINEN
LAUNDRY
STWD. LKR.
ELECT. STORES
CREW'S MESS



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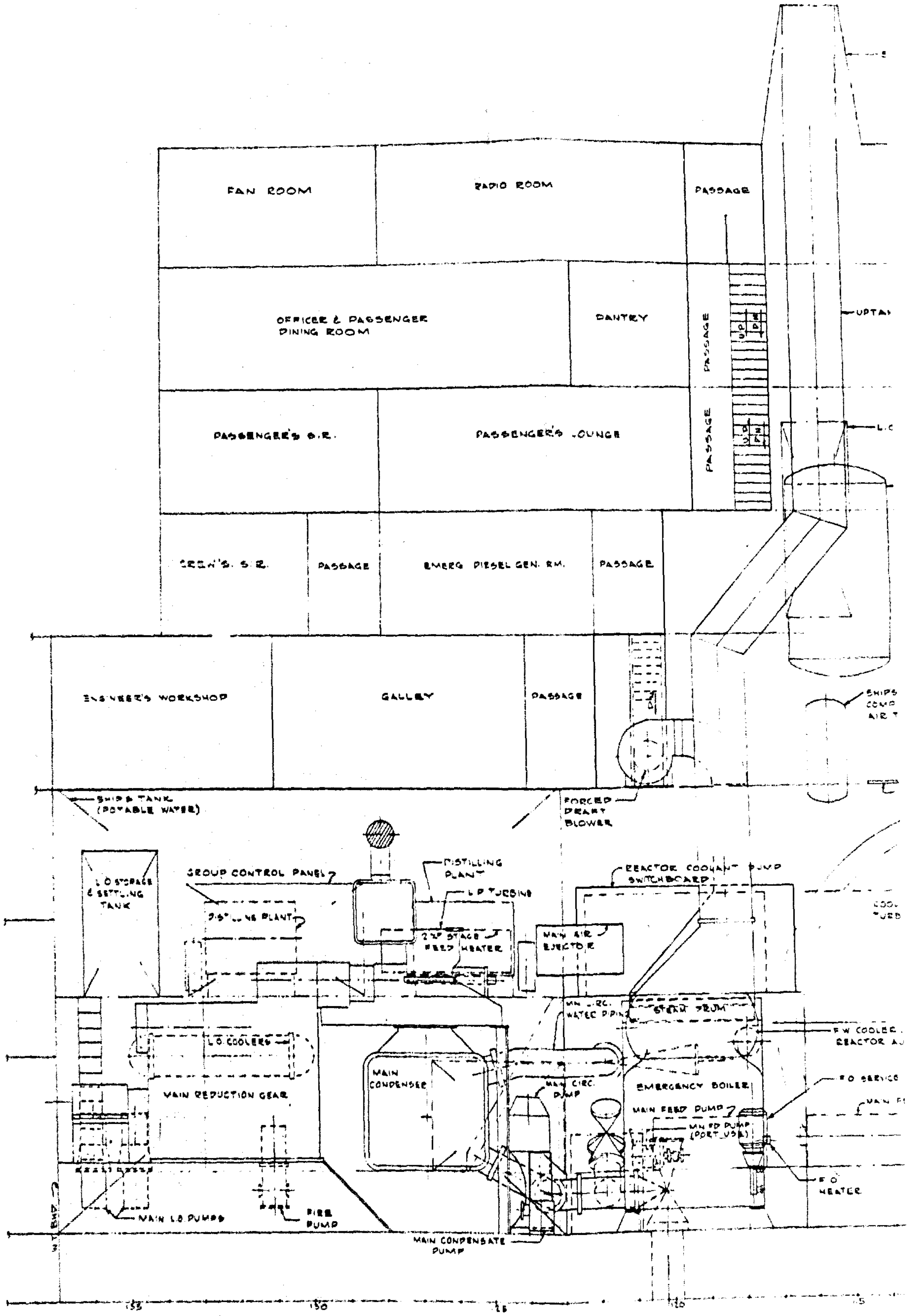
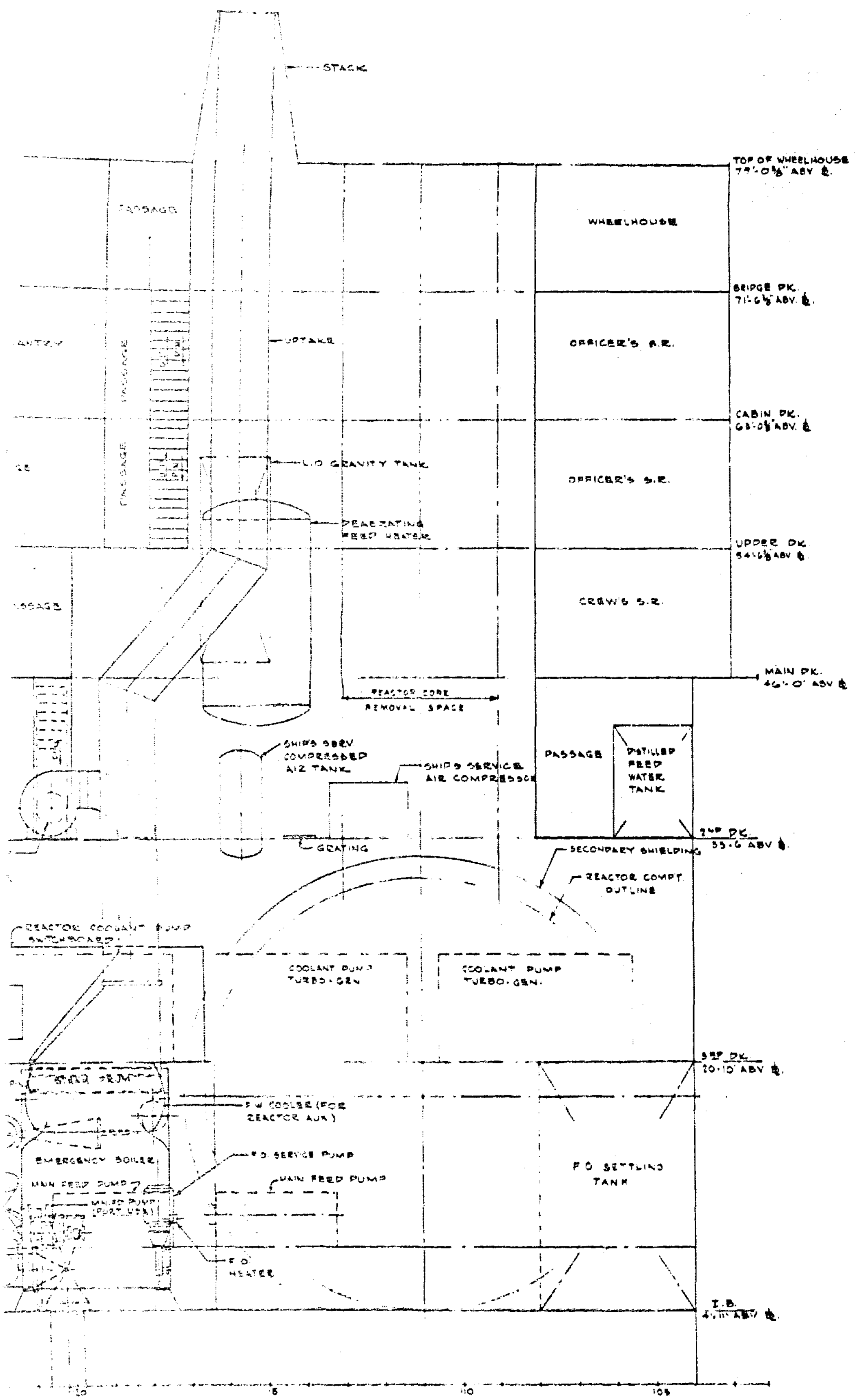
9-15-55

PLAN VIEW-2ND DECK.



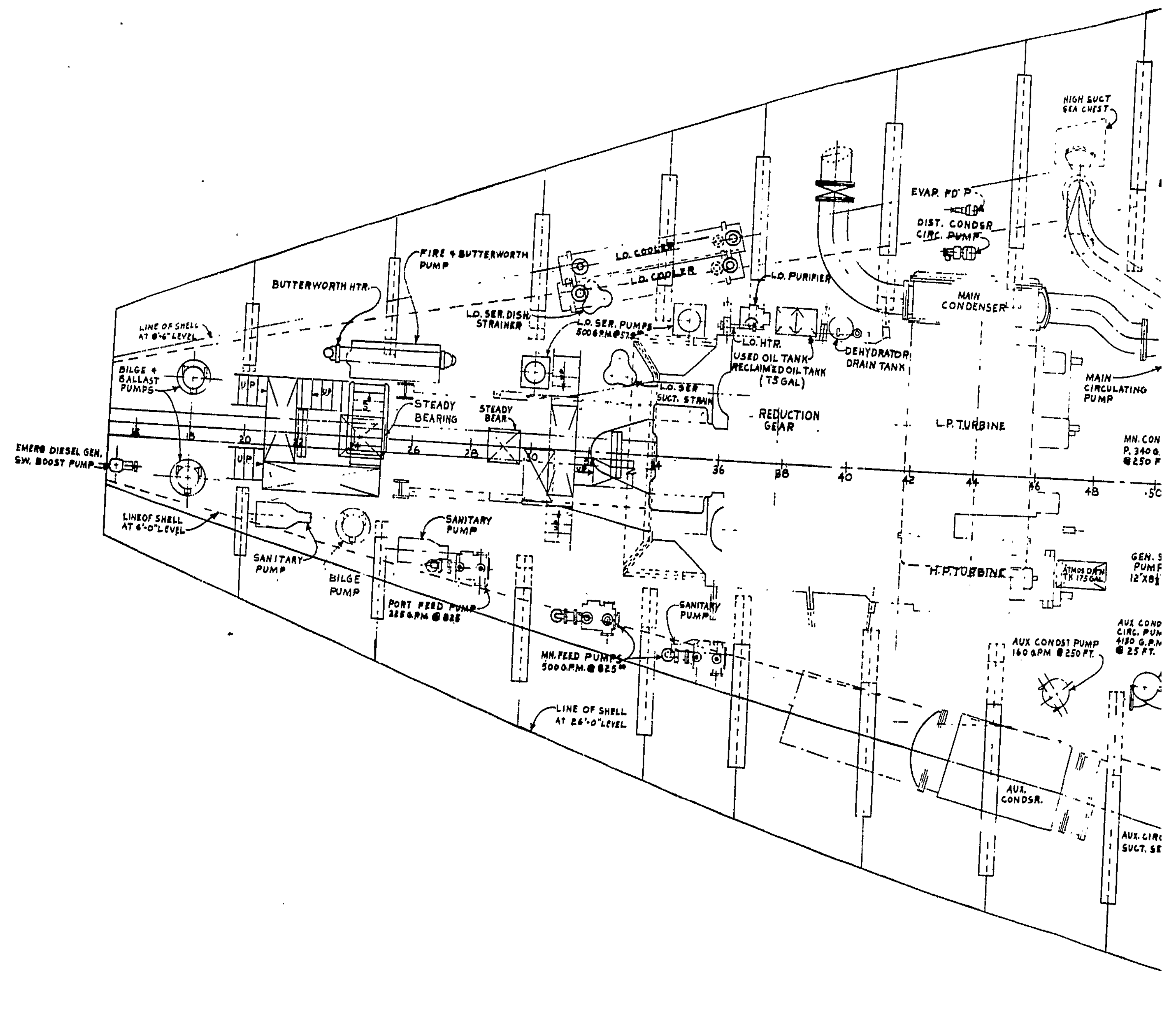
ELEVATION - ₵ LKG. TO POR
MACHINERY ARRGT



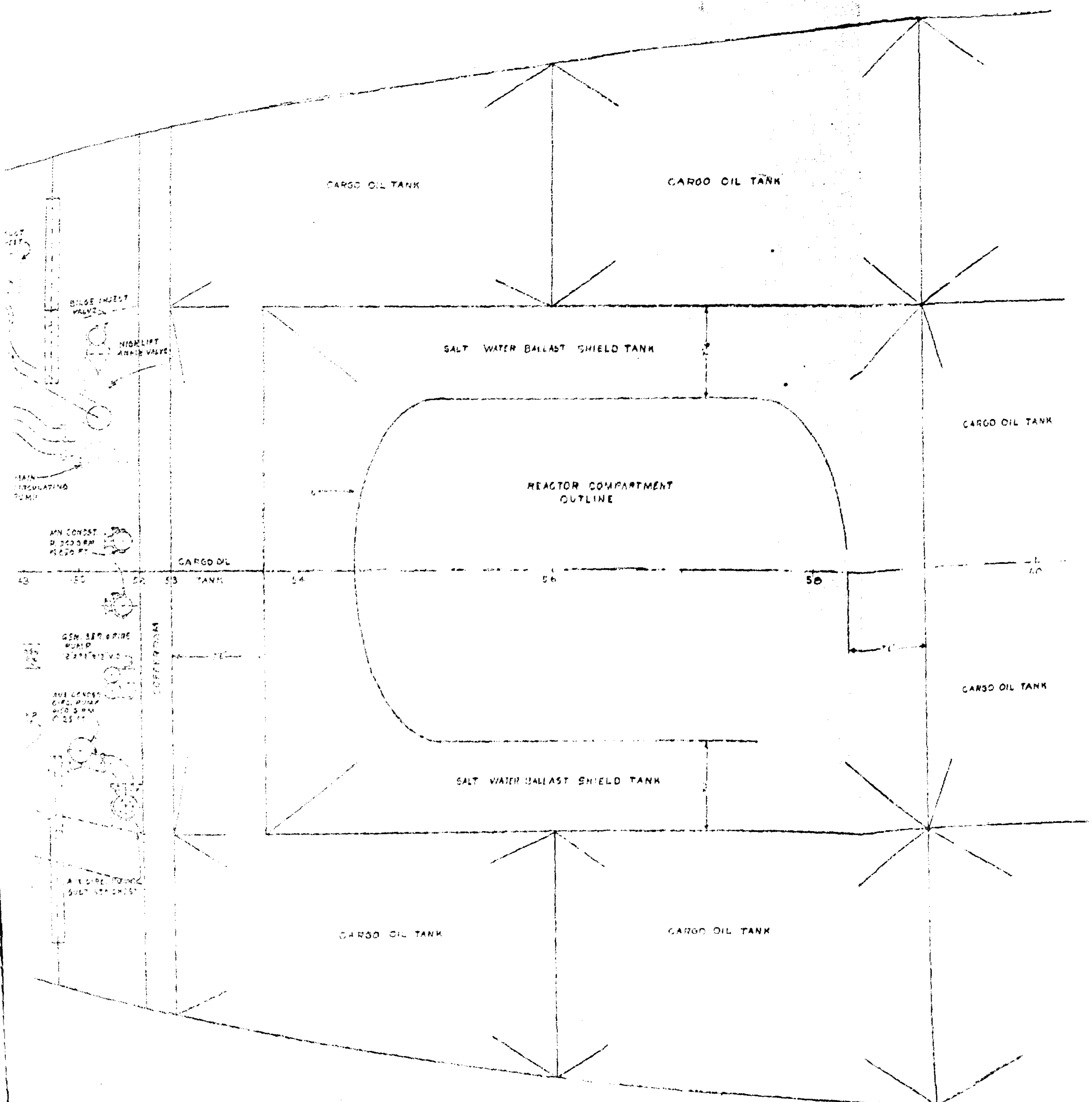
ELEVATION - ℄ LKG. TO PORT
MACHINERY ARRGT.

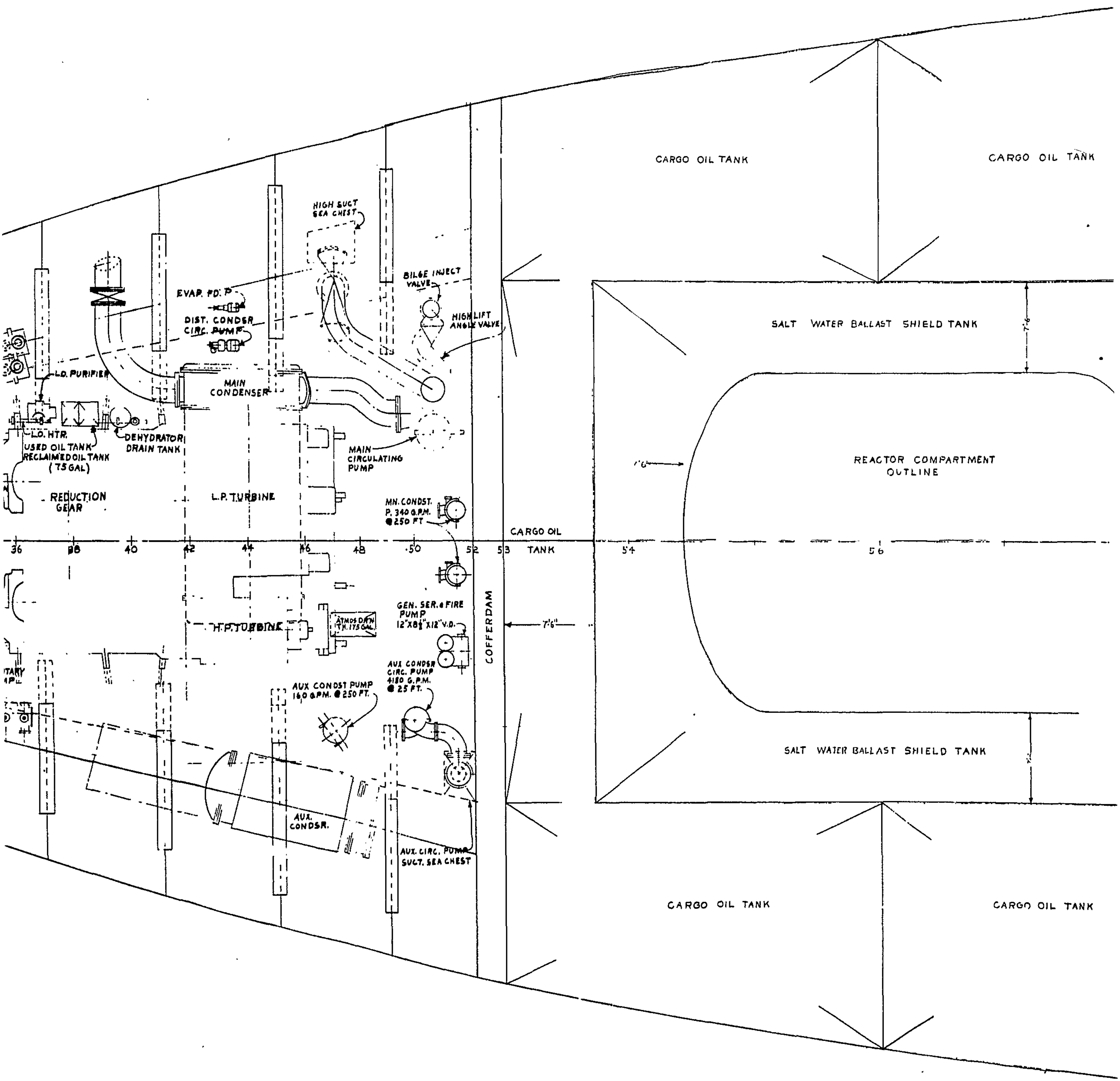
DRAWN B Jones
8-15-55

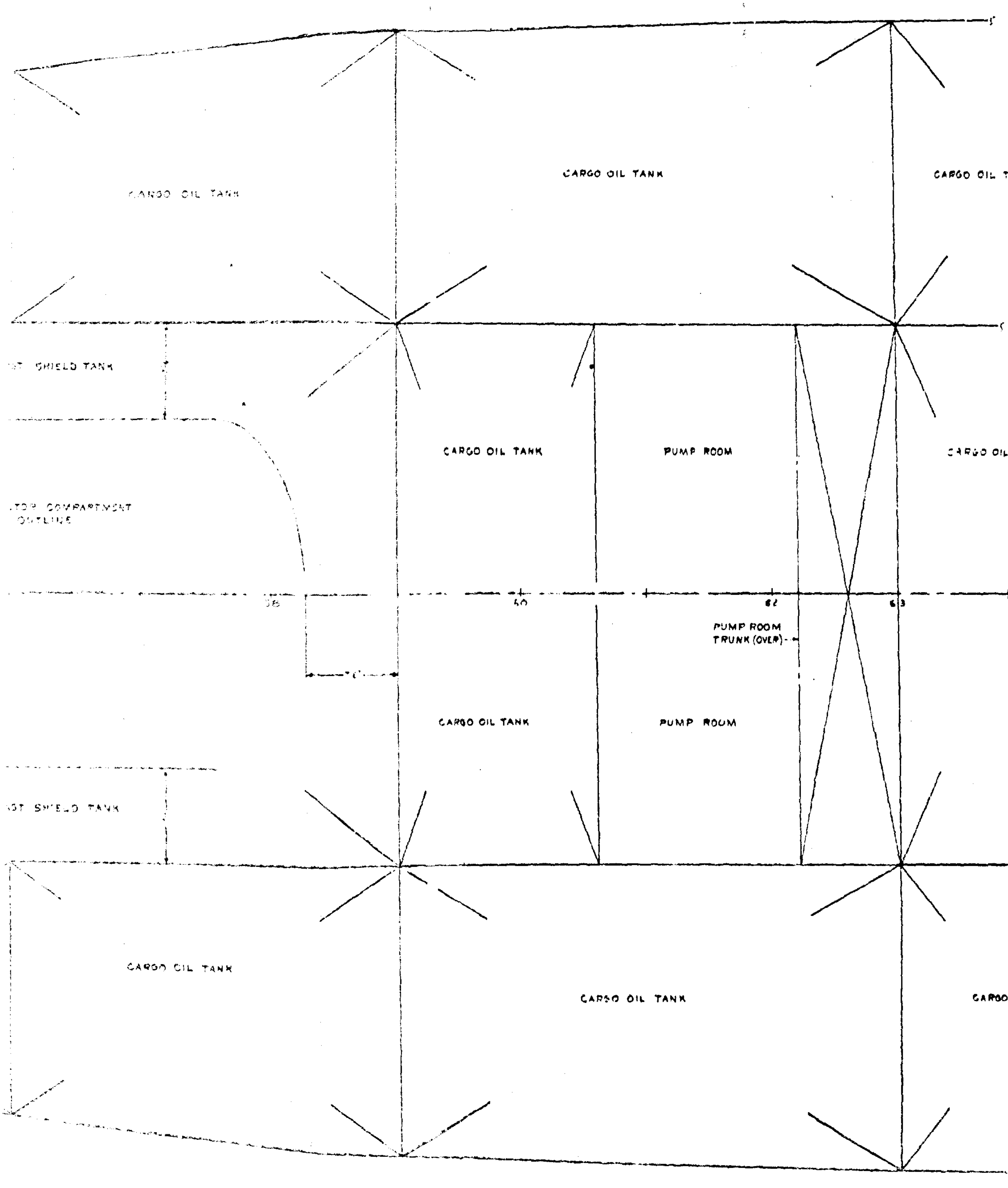
FIG NO 21



HIGH SUCT SEA CHEST
EVAP. FD. P.
DIST. CONDSR CIRC. PUMP
FIRE & BUTTERWORTH PUMP
BUTTERWORTH HTR.
L.O. COOLER
L.O. COOLER
L.O. PURIFIER
MAIN CONDENSER
LINE OF SHELL AT 6'-6" LEVEL
L.O. SER. DISH. STRAINER
L.O. SER. PUMPS
L.O. HTR.
DEHYDRATOR DRAIN TANK
USED OIL TANK RECLAIMED OIL TANK (75 GAL)
BILGE & BALLAST PUMPS
L.O. SER SUCT. STRAIN
MAIN CIRCULATING PUMP
STEADY BEARING
STEADY BEAR.
REDUCTION GEAR
L.P. TURBINE
EMERG DIESEL GEN. SW. BOOST PUMP
20
26
28
30
34
36
38
40
42
44
46
48
50
LINE OF SHELL AT 6'-0" LEVEL
SANITARY PUMP
SANITARY PUMP
BILGE PUMP
PORT FEED PUMP
H.P. TURBINE
ATMOS DRN TK 175 GAL
SANITARY PUMP
MN. FEED PUMPS
AUX CONDST PUMP 160 G.P.M @ 250 FT.
LINE OF SHELL AT 26'-0" LEVEL
AUX. CONDSR.


CARGO OIL TANK
CARGO OIL TANK
BILGE INJECT VALVE
HIGHLIFT
SALT WATER BALLAST SHIELD TANK
CARGO OIL TANK
REACTOR COMPARTMENT OUTLINE
MAIN CIRCULATING PUMP
CARGO OIL
TANK
54
56
58
COFFERDAM
CARGO OIL TANK
SALT WATER BALLAST SHIELD TANK
CARGO OIL TANK
CARGO OIL TANK

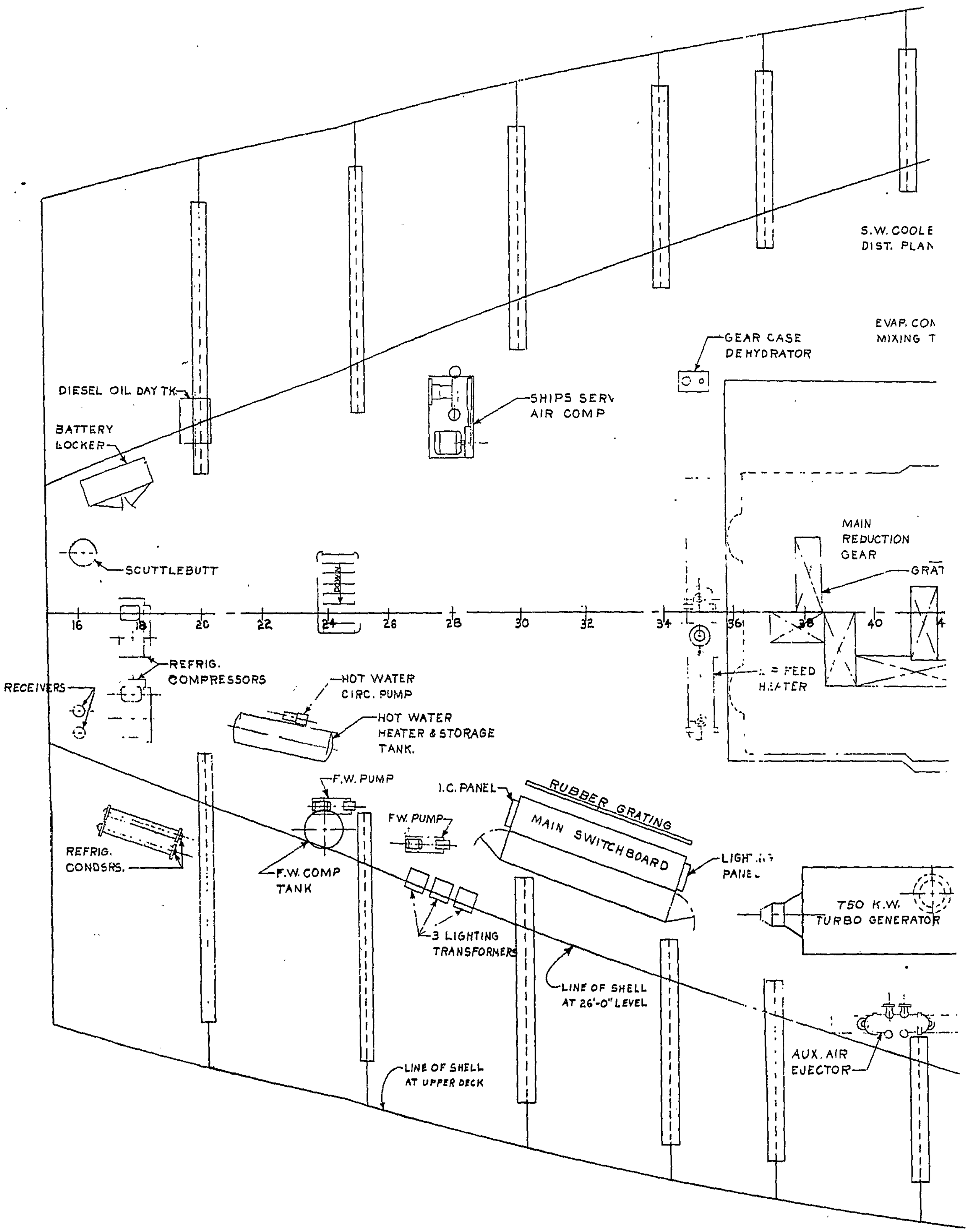

CARGO OIL TANK
CARGO OIL TANK
HIGH SUCT SEA CHEST
BILGE INJECT VALVE
HIGH LIFT ANGLE VALVE
EVAP. FD. P.
DIST. CONDSR CIRC. PUMP
SALT WATER BALLAST SHIELD TANK
L.O. PURIFIER
MAIN CONDENSER
L.O. HTR.
USED OIL TANK
RECLAIMED OIL TANK (75 GAL)
DEHYDRATOR DRAIN TANK
MAIN CIRCULATING PUMP
REACTOR COMPARTMENT OUTLINE
REDUCTION GEAR
L.P. TURBINE
MN. CONDST. P. 340 G.P.M. @ 250 FT.
CARGO OIL TANK
36
38
40
42
44
46
48
50
52
53
54
56
GEN. SER. & FIRE PUMP 12"X8½"X12" V.D.
ATMOS DRN TK. 175 GAL.
H.P. TURBINE
COFFERDAM
7'6"
AUX CONDSR CIRC. PUMP 4180 G.P.M. @ 25 FT.
AUX CONDST PUMP 16 G.P.M. @ 250 FT.
SALT WATER BALLAST SHIELD TANK
AUX. CONDSR.
AUX. CIRC. PUMP SUCT. SEA CHEST
CARGO OIL TANK
CARGO OIL TANK



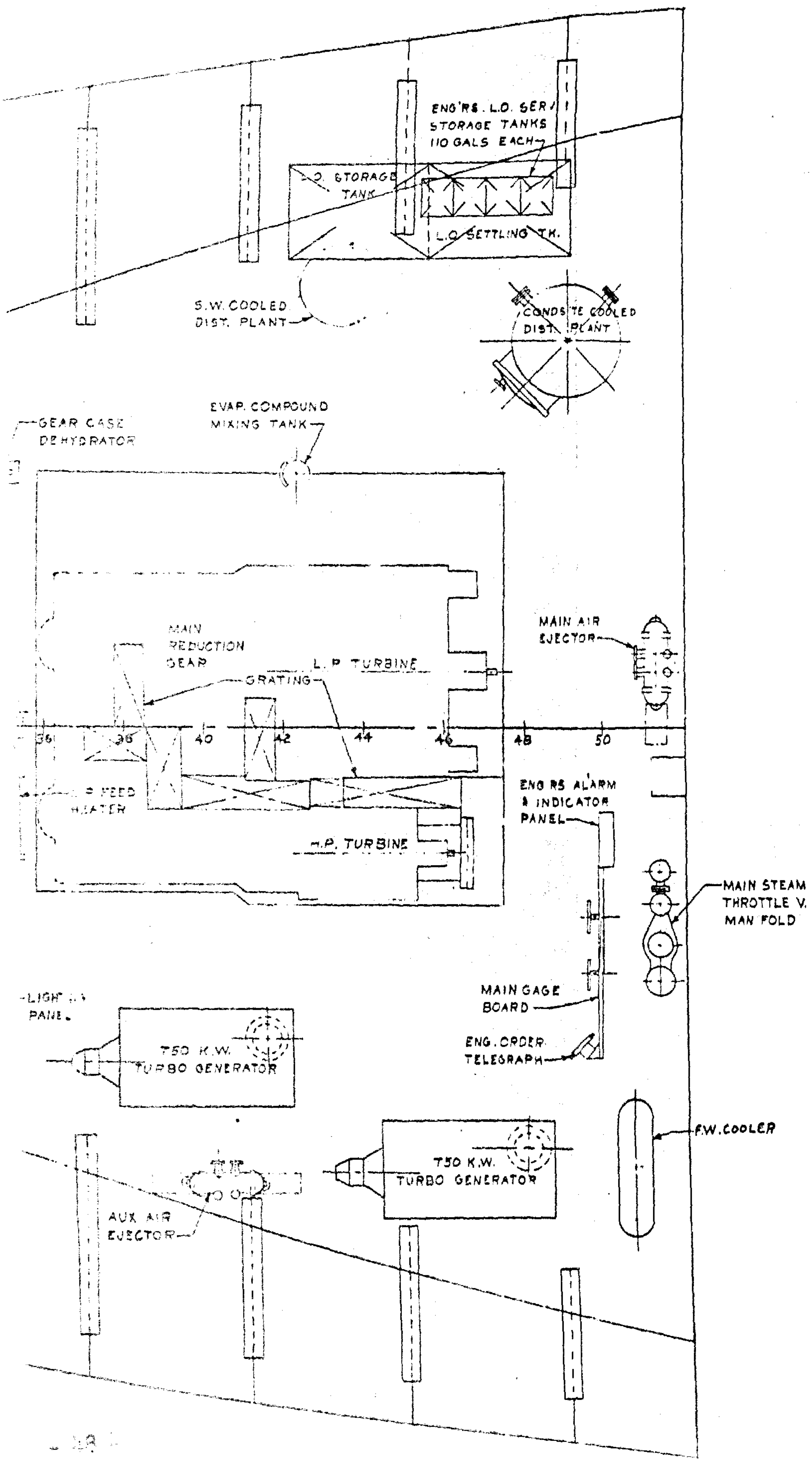
PROPOSED NUCL
POWERED TANKE

PLAN VIEW
LOWER LEVEL

FIG. NO. 22



S.W. COOLE
DIST. PLAN
EVAP. CON
MIXING T
GEAR CASE DEHYDRATOR
DIESEL OIL DAY TK.
SHIPS SERV AIR COMP
BATTERY LOCKER
MAIN REDUCTION GEAR
SCUTTLEBUTT
DOWN
16
18
20
22
24
26
28
30
32
34
36
38
40
REFRIG. COMPRESSORS
HOT WATER CIRC. PUMP
RECEIVERS
HOT WATER HEATER & STORAGE TANK.
F.W. PUMP
I.C. PANEL
RUBBER GRATING
MAIN SWITCHBOARD
F.W. PUMP
REFRIG. CONDSRS.
F.W. COMP TANK
750 K.W. TURBO GENERATOR
3 LIGHTING TRANSFORMERS
LINE OF SHELL AT 26'-0" LEVEL
AUX. AIR EJECTOR
LINE OF SHELL AT UPPER DECK



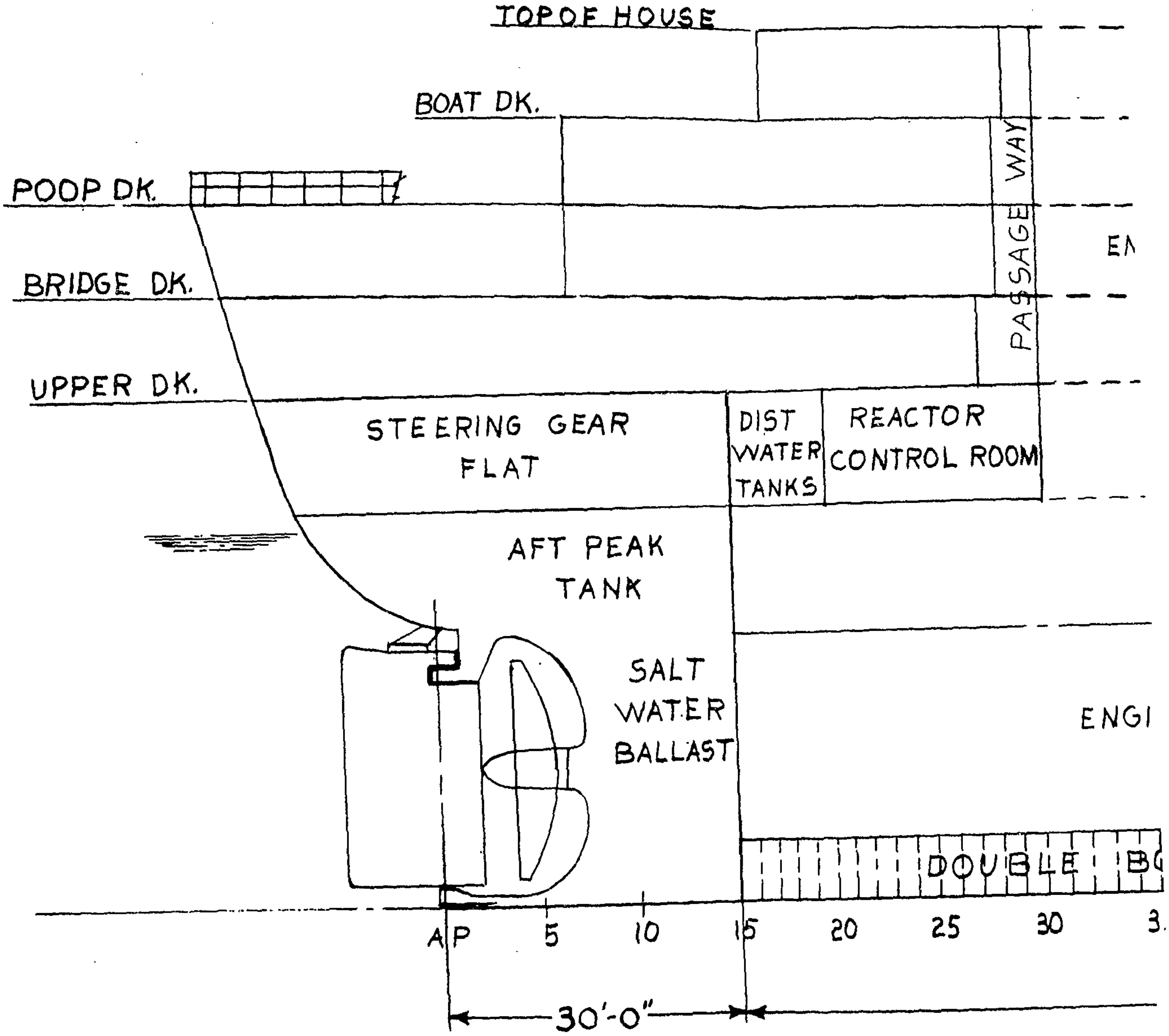
PROPOSED NUCLEAR POWERED TANKER

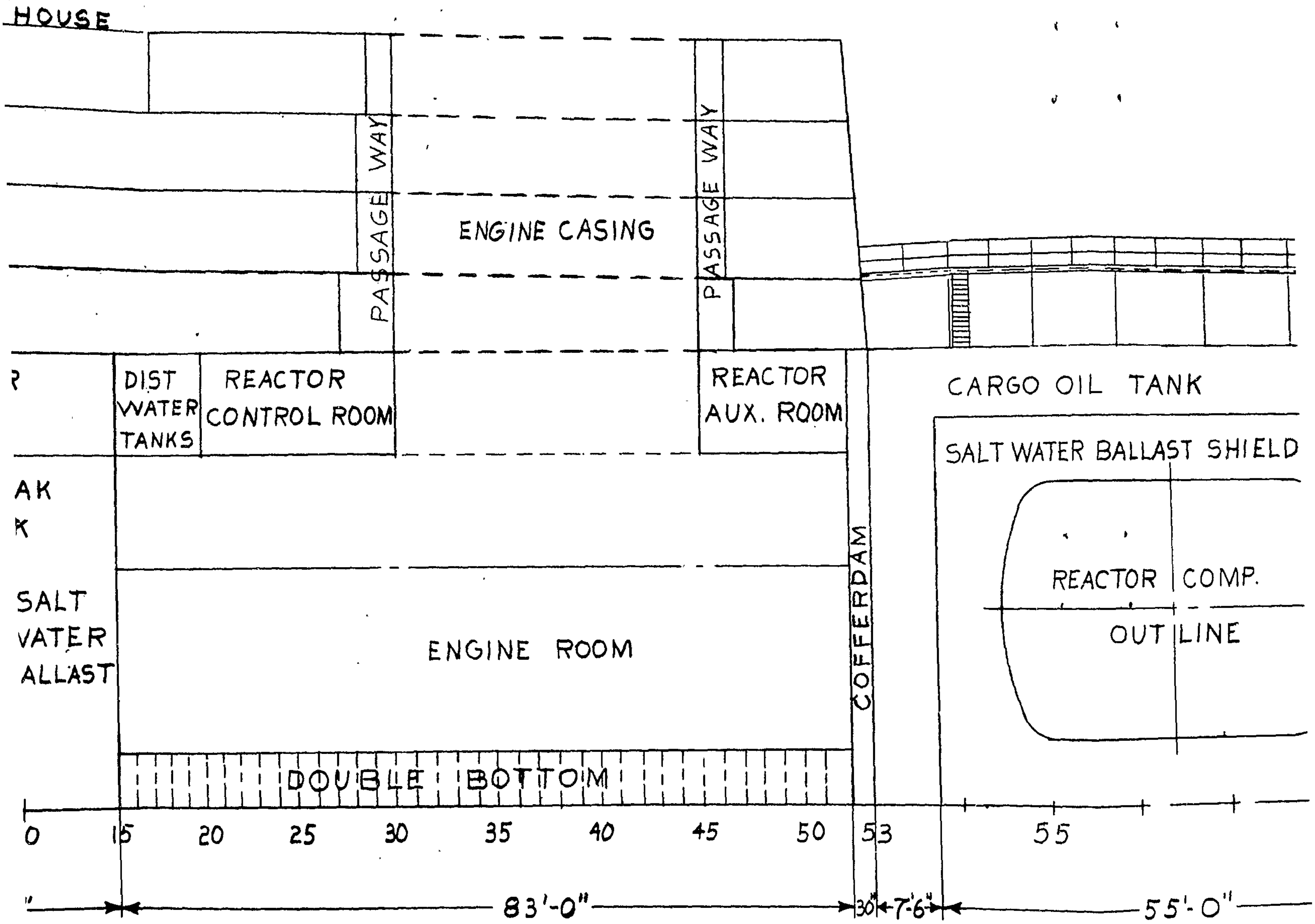
PLAN VIEW
26' LEVEL

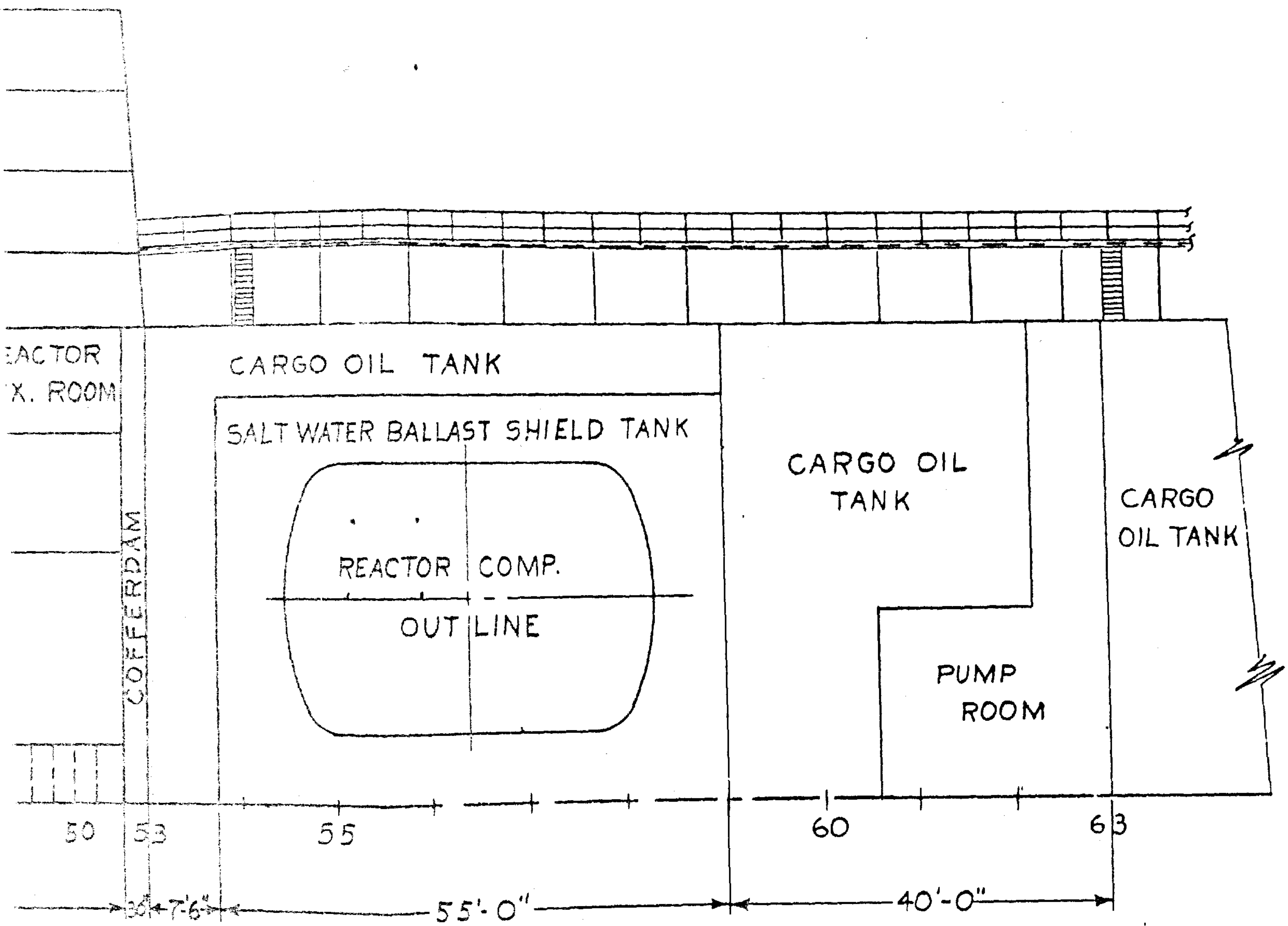
DRAWN BY: M. MARINIAN

10-12-55

FIG NO. 23


TOP OF HOUSE
BOAT DK.
POOP DK.
BRIDGE DK.
UPPER DK.
PASSAGE WAY
STEERING GEAR FLAT
DIST WATER TANKS
REACTOR CONTROL ROOM
AFT PEAK TANK
SALT WATER BALLAST
DOUBLE
AP
5
10
15
20
25
30
30'-0"


HOUSE
PASSAGE WAY
ENGINE CASING
PASSAGE WAY
DIST WATER TANKS
REACTOR CONTROL ROOM
REACTOR AUX. ROOM
CARGO OIL TANK
SALT WATER BALLAST SHIELD
AK
K
SALT
VATER
ALLAST
REACTOR COMP.
OUT LINE
ENGINE ROOM
COFFERDAM
DOUBLE BOTTOM
0
15
20
25
30
35
40
45
50
53
55
83'-0"
30"
7'-6"
55'-0"

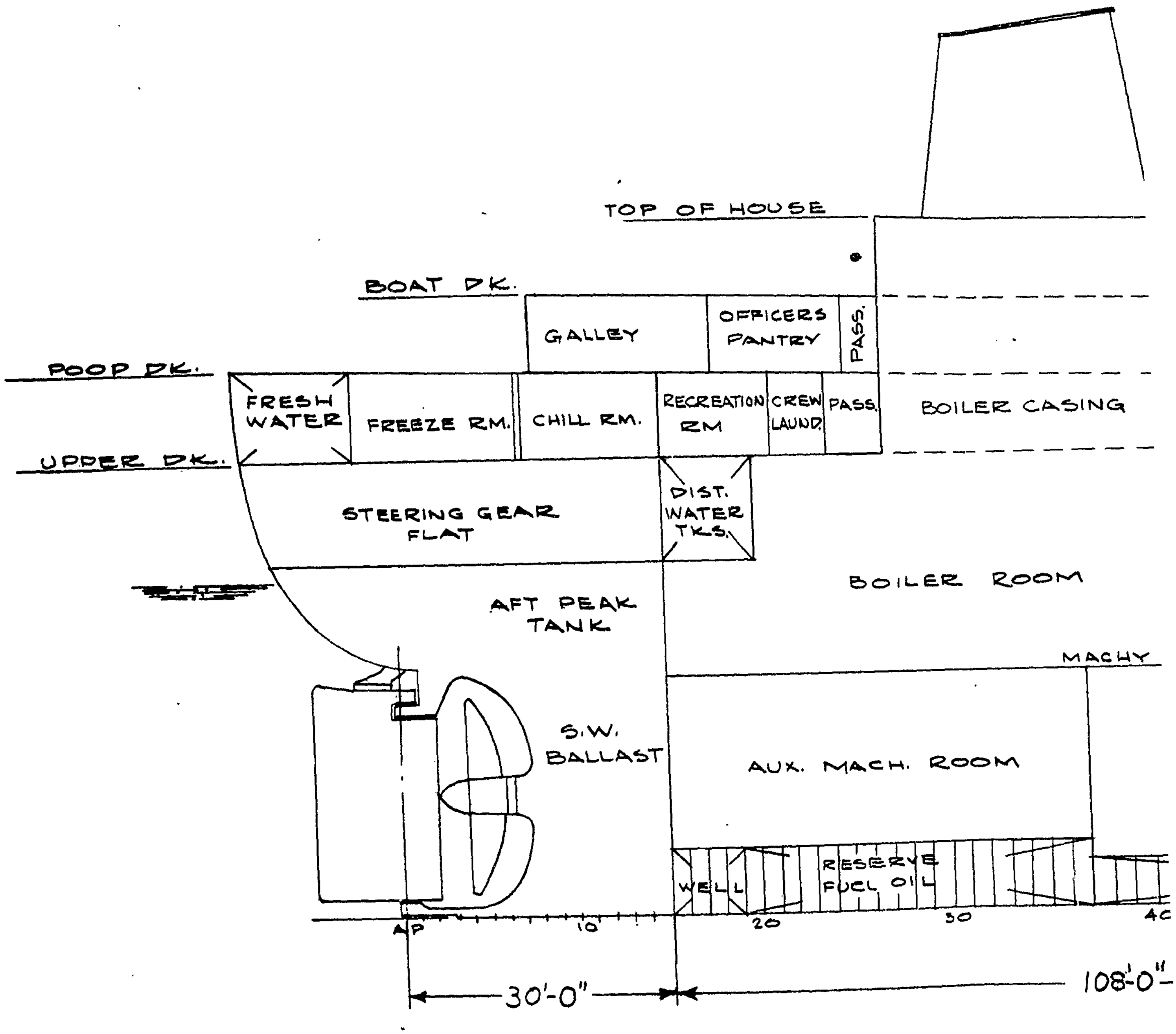


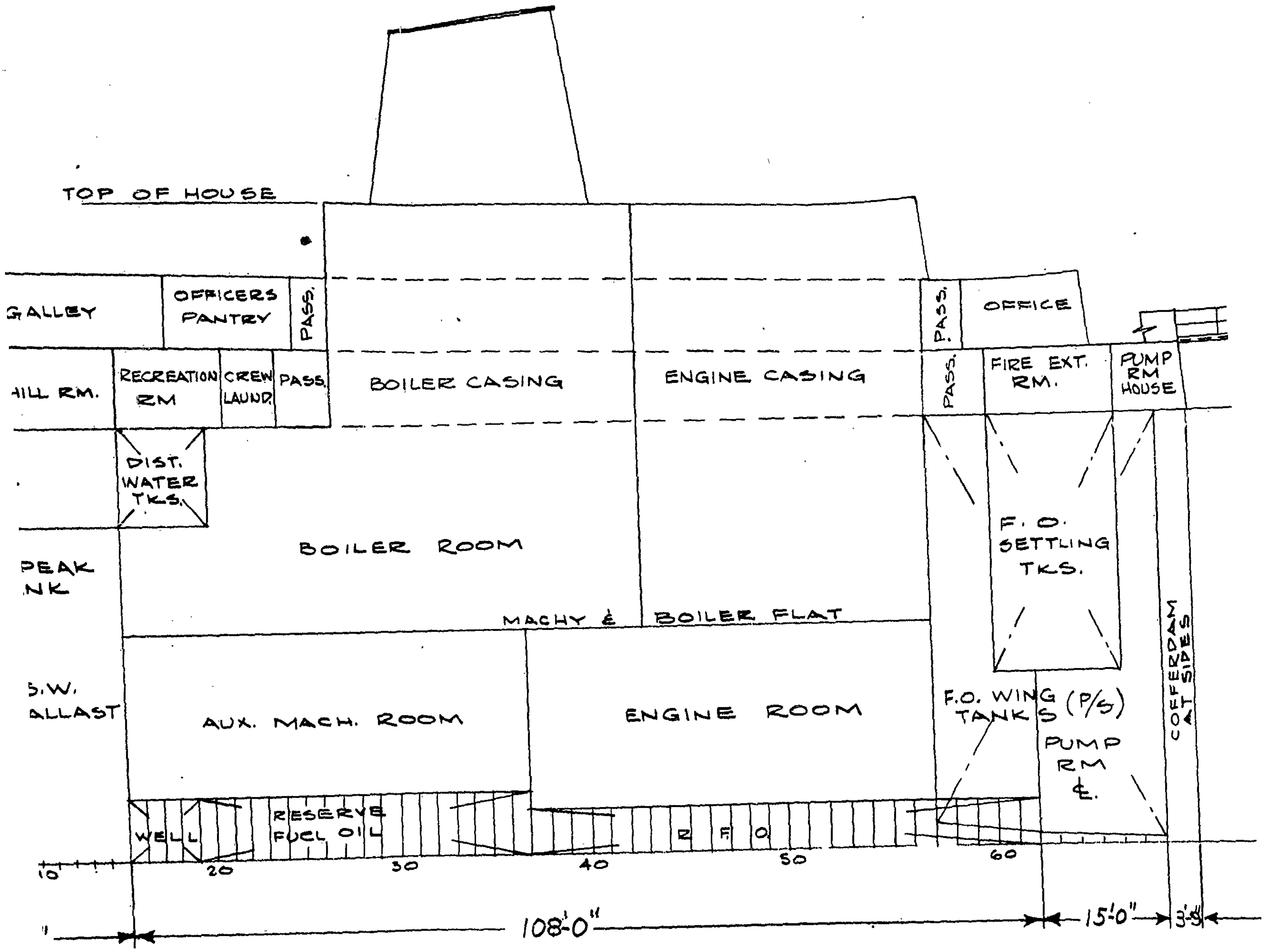
PROPOSED NUCLEAR
POWERED TANKER

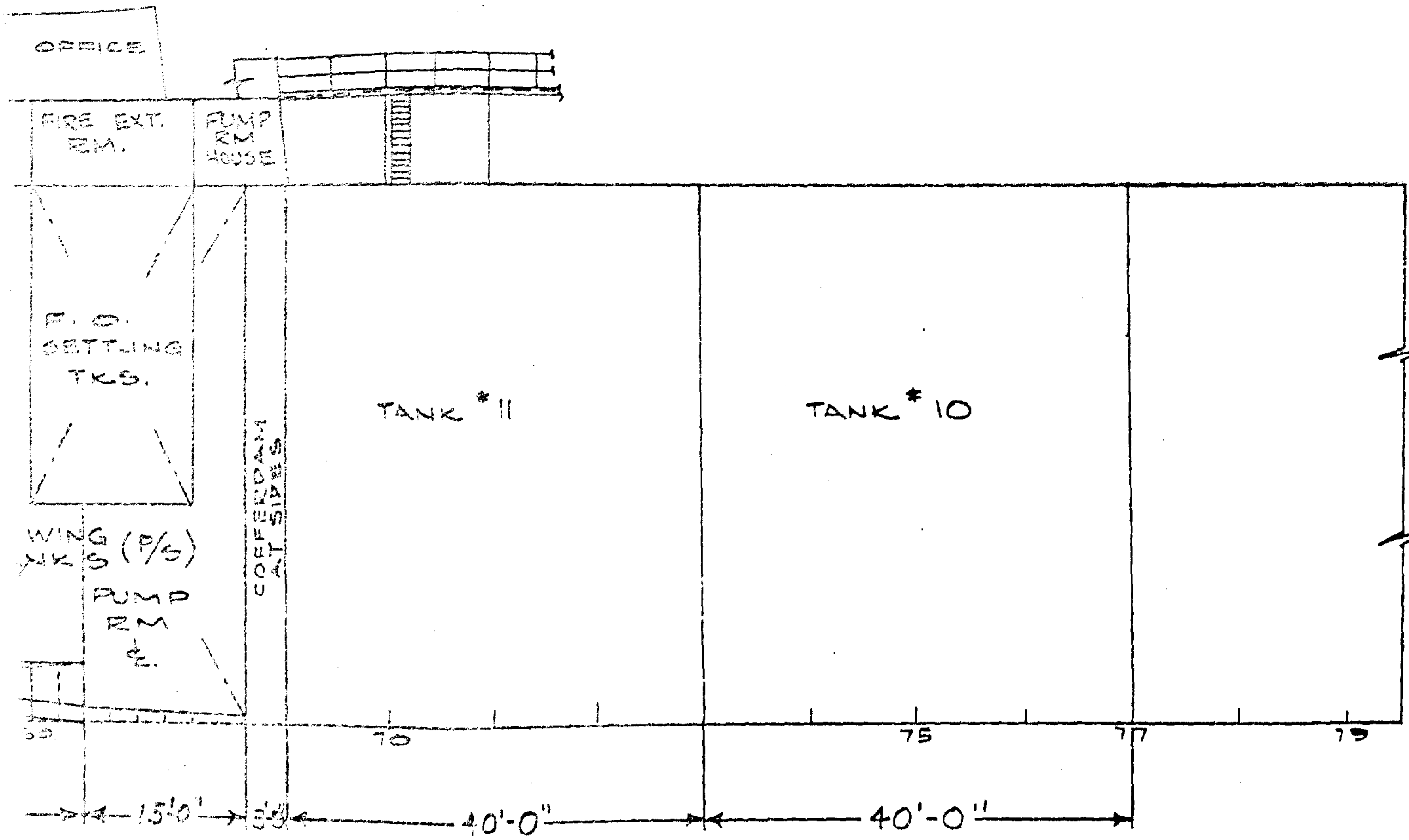
INBOARD PROFILE (AFT)

DRAWN BY: M. MARINIAK
10-12-55

FIG. NO. 25


TOP OF HOUSE
BOAT DK.
GALLEY
OFFICERS PANTRY
PASS.
POOP DK.
FRESH WATER
FREEZE RM.
CHILL RM.
RECREATION RM
CREW LAUND.
PASS.
BOILER CASING
UPPER DK.
STEERING GEAR FLAT
DIST. WATER TKS.
BOILER ROOM
AFT PEAK TANK
MACHY
S.W. BALLAST
AUX. MACH. ROOM
WELL
RESERVE FUEL OIL
AP
10
20
30
40
30'-0"
108'-0"


TOP OF HOUSE
GALLEY
OFFICERS PANTRY
PASS.
PASS.
OFFICE
HILL RM.
RECREATION RM
CREW LAUND.
PASS.
BOILER CASING
ENGINE CASING
PASS.
FIRE EXT. RM.
PUMP RM HOUSE
DIST. WATER TKS.
F. O. SETTLING TKS.
PEAK
NK
BOILER ROOM
MACHY & BOILER FLAT
COFFERDAM AT SIDES
S.W.
ALLAST
AUX. MACH. ROOM
ENGINE ROOM
F.O. WING TANKS (P/S)
PUMP RM
℄
WELL
RESERVE FUEL OIL
R F O
10
20
30
40
50
60
108'-0"
15'-0"
3'-3"



INBD. PROFILE OF
OIL FIRED
TANKER.

DRAWN BY: B. JONES
10-18-55

FIG. NO. 2[illegible]